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Marine Studies of San Pedro Bay, California. Part 16 Ecological Changes in Outer Los Angeles-Long Beach Harbors Following Initiation of Secondary Waste Treatment and Cessation of Fish Cannery Waste Effluent

University of Southern California, Los Angeles

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A REPORT FOR THE CITY OF LOS ANGELES DEPARTMENT OF PUBLIC WORKS
BUREAU OF ENGINEERING, FOR THE TERMINAL ISLAND TREATMENT PLANT
AND
THE ENVIRONMENTAL PROTECTION AGENCY, REPORT TO CONGRESS
ON SEAFOOD WASTE EFFLUENTS, FOR THE TUNA RESEARCH FOUNDATION

by
Harbors Environmental Projects

edited by
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INSTITUTE FOR MARINE AND COASTAL STUDIES
ALLAN HANCOCK FOUNDATION 139
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MARINE STUDIES OF SAN PEDRO BAY, CALIFORNIA PART 16

April, 1979

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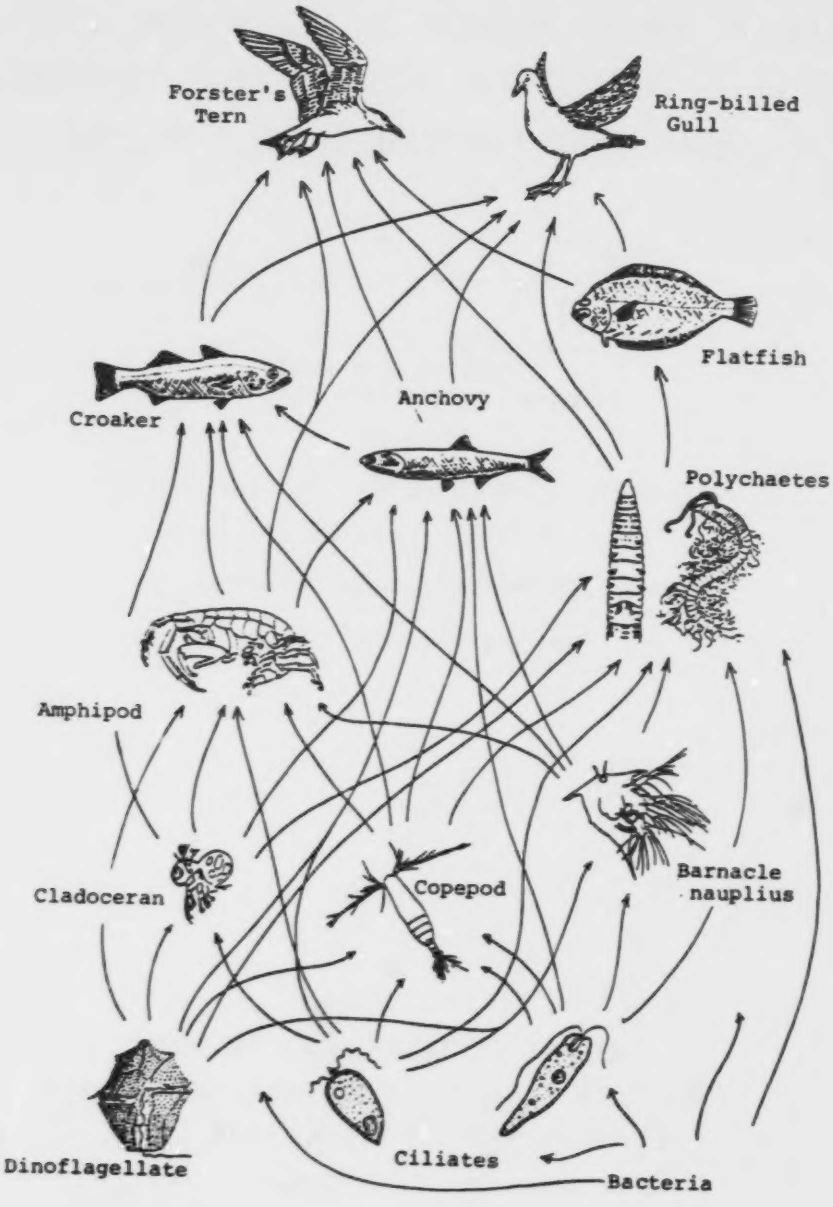

HARBOR FOOD WEB DIAGRAM

FOREWORD

The present report summarizes ecological investigations on the effects of effluents from fish cannery wastes and the municipal treatment plant (TITP) in outer Los Angeles Harbor over a period of some eight years. Field investigations, experimental field and laboratory investigations, and computer analyses have been carried out under the following estimated conditions and times:

1971-74	Prior to Dissolved Air Flotation (DAF) pre-treatment of cannery wastes; urban primary TITP wastes
1975-77	DAF treated cannery wastes; primary TITP wastes
Apr-Oct 77	DAF cannery wastes; secondary TITP effluent
Oct 77-Jan 78	Canneries hook up to TITP; secondary TITP effluent
Jan-May 78	Variable secondary TITP (Chlorination Mar 9-Aug 30, 78)
Mar 9-Aug 30 78	Chlorination of TITP
June-Aug 78	TITP upset, primary plus suspended solids
Sept-Dec 78	Secondary TITP

The 1976-78 field and laboratory investigations were funded by the City of Los Angeles Department of Public Works for their Envirnomental Impact Report (EIR) on the Terminal Island Treatment Plant outfall location.

The preparation of a special report on this research to the Environmental Protection Agency, Washington, D.C. was funded by the Tuna Research Foundation in order to make current information available to the Environmental Protection Agency for incorporation into their Report to Congress on the effects of fish cannery effluents on marine waters.

On-going research on Los Angeles and Long Beach Harbors (San Pedro Bay) since 1970 has been funded by a number of public agencies and private entities. These include: The Port of Los Angeles, the Port of Long Beach, the USC Sea Grant Program (Dept. of Commerce, NOAA), the U.S. Army Corps of Engineers, Pacific Lighting Service Corporation, Southern California Gas Company, and many others. The studies have often been cooperatively funded and multidisciplinary in scope. Fourteen volumes of the series Marine Studies of San Pedro Bay, California and a number of special reports by Harbors Environmental Projects have been published on Los Angeles-Long Beach Harbors since 1972 (University of Southern California).

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Cover photo: USC Marine Facility in Los Angeles Harbor,
courtesy of John D. Soule

EXECUTIVE SUMMARY

EVALUATION OF RESULTS RELATED TO BIOENHANCEMENT

Following the intensive control of toxic wastes and cleanup efforts mandated by the Los Angeles Regional Water Quality Control Board in 1970, the formerly depauperate harbor experienced an enormous increase in species, higher taxa, and populations unprecedented in the area,in the period from 1971 to 1974.

The harbor was, in 1973-1974, the richest soft-bottomed marine area in southern California. It was dependent upon the nutritious organic fish processing wastes and primary Terminal Island Treatment Plant (TITP) wastes which were mixed by the currents and winds in the area. The harbor was defined as "bioenhanced" on the basis of:

- species diversity
- evenness, hierarchical diversity
- total populations, richness
- biomass
- presence of essential food web species
- species of commercial/recreational value
- rare or endangered species
- potential for mariculture

In 1977-78, studies similar to the 1973-74 investigations were made to assess the present state of the harbor on the basis of the same criteria, following the conversion of cannery effluents and domestic wastes to secondary treatment in the Terminal Island Treatment Plant (TITP). Harbor richness has been reduced. The greatest impacts occurred after DAF pre-treatment of cannery wastes began. Lesser impacts occurred after secondary treatment was put in operation. In summary:

- The shift in nutrients is from complex organic proteins, amino acids, fats, carbohydrates and ammonia to production of nitrate and nitrite. These mineralized nutrients have only limited availability to the food web, by way of phytoplankton. Amines are also present, which are not generally utilized.

- The bird populations were down to forty percent of 1973-74 levels. The gull species experienced the greatest loss, greater than threefold.

- The fish populations in 1978 were down from 10 to 20 times for white croaker and perhaps 100-fold for anchovies. These were the two most common species in the harbor in 1972-74. The average number of species per trawl dropped from 10 to 6. Near the TITP outfall the species averaged 9.5, indicating its importance in supplying the only remaining attraction for the fish.

- The phytoplankton population means, measured by chlorophyll *a*, are grossly similar for both periods. However, the productivity and assimilation ratios, representing the rates at which the phytoplankton produce food for other organisms, are drastically reduced, presumably due to loss of nutrients, or to inhibition. The drop in consumer populations would indicate that a decrease in the net phytoplankton crop has occurred.

- Zooplankton are perhaps least affected, since they are carried into the harbor on the changing tides; however, endemic harbor populations exist. Species diversity has been slightly increased overall, but the total numbers of organisms have varied greatly. It is likely that the greatly reduced fish population resulted in much reduced predation on zooplankton. Thus a deteriorating ecosystem which resulted in a decreased zooplankton production could still appear to have an increased zooplankton stock. There are also limiting factors for the zooplankton population, such as a reduction in nutrients. Species composition was altered as well.

- Benthic organisms in the enhanced area in 1973-74 numbered greater than 25 species and 35,000 organisms per m^2. The mean species diversity for the outer harbor increased steadily from 1971 through 1976. It dropped to 1972-73 levels in 1978.

  The mean numbers of organisms per m^2 rose from 2861 in 1971 to 27,806 in 1973, a tenfold increase. They declined in 1975 (coincident with installation of dissolved air flotation (DAF) treatment by the canneries) to 63% of 1973 levels, and dropped to 27.6% in 1976, 27.7% in 1977, and 26.8% of 1973 levels in 1978. Some of the previously most common species that were fed on by bottom fish have decreased or disappeared at times. This could seriously affect fish larvae or adults at crucial periods in their life cycles.

- Fish egg and larvae surveys led to the conclusion that the total numbers were up somewhat in 1978 over 1973-74 levels in the harbor. Anchovy eggs had virtually disappeared instead of being a major component. Improved survey techniques biased the data in favor of the increase, but the large drop in predator fish species may have resulted in increased survival.

- Microheterotrophs (bacteria, fungi, protists, etc.) dropped 30-fold in 1978 after conversion of TITP to secondary treatment and cessation of cannery effluents. Since filter-feeders and deposit feeders are dependent in part on particulate detritus to which bacteria are attached, this represents an enormous loss to those food chain organisms. Benthic organisms in the soft bottom harbor were therefore reduced.

  The loss of bacterial populations will also be reflected in the ability of the harbor to assimilate wastes, since they were an important link in recycling material.

- Computer analyses indicated that the benthic populations were much more specifically influenced by cannery and TITP effluent events than were zooplankton populations. In some periods, natural physical variables were shown to be more important, while in other periods the phytoplankton (and its controlling factors) were more significant.

- In bioassay/toxicity tests there was no evidence that the secondary TITP effluent was toxic at any concentration. Variations in effluent quality could alter that at any time if toxic materials, which could not be removed in treatment, were introduced into the system.

- Biostimulation and growth experiments in the field and laboratory showed that both pre-DAF cannery waste and TITP secondary waste could sustain or stimulate growth in phytoplankton, some invertebrates and some fish. Bioenhancement is thus clearly possible with either or both of these wastes.

- TITP effluent is a beneficial nutrient source in the harbor, although the levels are much reduced over previous nutrient regimes.

- The pre-DAF cannery waste and TITP primary wastes provided a much richer ecosystem. The change to solely TITP secondary waste impacted most severely the food chain or web represented as the following: organics/detritus → bacteria → benthic polychaete worms → demersal fish → birds. This is schematic and thus oversimplified.

- There was little impact on the total phytoplankton crop but there may have been a shift in species away from those favored by certain fish larvae or juveniles. The total zooplankton stock also appeared to be little altered. Reduced predation may contribute to the apparent stability of the plankton populations. This food chain or web is represented as follows: $NO_2/NO_3/NH_3$ → phytoplankton → zooplankton → pelagic fish → birds. Again, this is oversimplified but indicative of the difference in the system. It selects for species with one set of food needs and selects against others.

Fish Populations

The mean number of fish per trawl in the Los Angeles-Long Beach outer harbors experienced a four-fold drop between 1973 and 1978; a small temporary increase occurred in 1977, but it was followed by a continued precipitous drop in 1978. This contrasts with an almost two-fold increase between 1972-73 and 1977, in party boat catch in the area outside the harbor, a curve that was interrupted only by small decreases in 1975-76. Thus the trend in the harbor has been distinctly downward over the 1973-1978 period.

There is no indication that cessation of cannery discharges has been beneficial to harbor fish populations; rather, it appears that the change has been detrimental. It is impossible to state at this time that cessation is *the* only cause of the large decrease because of the many unknowns. However, the 1973-74 drop may have been a natural regression from the peak of a cycle which resulted when the control of toxic wastes was instituted in 1970-71. The drop preceded in time the 1975 installation of DAF treatment of cannery wastes and would presumably have leveled off to a more stable level. The precipitous drop in December 1977 coincided precisely with the tremendous drop in nutrients due to the cessation of cannery effluents and diversion of all wastes to TITP secondary treatment, coupled with nutrient loss due to the drought. In July 1978, the peak return of fish to the harbor coincided with the peak period of TITP malfunction during which large amounts of BOD and suspended solids were released to the entire central outer harbor. The counts dropped again as soon as the malfunction was corrected.

The two important fish species were particularly affected. White croaker dropped 10- to 20-fold over the 1973-78 period. It was the principal fish caught by low income shore anglers, and now sells for about $3 per pound in local markets as "butterfish". Anchovy dropped by a factor of perhaps 100-fold in the same period. The harbor had previously been the home of a very large population of 0-1 yr age class anchovy. This compares with a 4-fold drop in the same period in anchovy stock offshore. The large drop in gull species in the harbor, which fed on anchovies and fish "gurry" (floating protein-fat coagulates), may be related to the decline in nutrients and hence in anchovies.

The TITP sewage outfall now seems to be the only nutrient area left in the harbor that shows larger fish populations than the other trawl stations. It is therefore very important to maintaining the now-small fish population in the harbor.

Bird Populations

The average number of all marine birds sighted per observation period in 1973-74 was 5,665, while the average number per period in 1978 was 2,280. This is a reduction of about 60%. The major differences occurred primarily in fall and winter months. The change in species numbers was varied; most loons and grebes increased, as did the Brown Pelican and cormorants. Among ducks, the abundant Surf Scoter suffered about a 60% decrease. The abundant Sanderling, among shorebirds, declined 11-fold.

All gull species declined; the Western Gull by a factor of 4, the California Gull by 23 times and Heermanns Gull by 2.5 times. These represent the largest numbers of birds.

The endangered Least Tern and Royal Tern increased, but all other terns decreased. However, Least Tern nesting had been disrupted during the 1973 and 1974 surveys by construction. Purposeful disruption occurred again in 1978 and no nesting occurred, but 85 nests had been present in 1977. Sightings are otherwise infrequent and the increase in 1978 is small.

Changes in bird populations may be due to the very large decrease in anchovies and/or in solid or particulate matter from the wastes. Liquid protein "salts out" in sea water and cannery wastes formerly contained some coagulates and particles which floated on the water and were fed upon by many birds.

Phytoplankton Resources

Monitoring of phytoplankton productivity, chlorophyll *a* (a photosynthetic pigment), and assimilation ratio in the outer Los Angeles Harbor was carried out before, during, and after changeover of the Terminal Island Treatment Plant to secondary waste treatment and the diversion of cannery wastes into the plant for treatment prior to discharge.

The chlorophyll *a* concentrations during this period showed similar annual patterns, indicating that the changes had not disrupted the development of phytoplankton populations. However, the levels of productivity and assimilation were substantially reduced by the conversion of the TITP sewage plant to secondary treatment in 1977, although these parameters appeared to follow the same seasonal periodicities as previously.

After the diversion of the cannery wastes into the treatment plant, completed in January 1978, further sharp reductions were found in both productivity and assimilation ratio. The cyclic pattern was obscured in 1978, but this may have been due, in part, to a major plant upset in the summer of 1978.

Zooplankton Resources

Species diversity of copepods and cladocerans is generally higher outside the harbor than it is inside, and appears to be higher in winter than in summer. Species diversity was reduced at the onset of TITP secondary treatment in April 1977, but was accompanied by a bloom of *Acartia tonsa*. A high-to-low gradient in diversity existed prior to full secondary treatment from station A1 (outside) to A3 (middle harbor) to A7 (outfalls). After full secondary, station A1 was still highest in diversity but A7 was next highest and A3, located between the two, was the lowest.

The so-called zone of enhancement in the harbor, if it still exists for zooplankton, has apparently retreated to the area around the TITP outfall, on the basis of initial analyses, but the concentration levels are lower as well.

In total concentrations, the ratio of A1:A7 was 1.5:1 before full secondary treatment of cannery wastes. The ratio of A1:A7 became 4:1 after full TITP secondary treatment. The numbers of organisms per m^3 were very low in the fall of 1977; they improved somewhat in 1978.

Benthic Resources

While the distributions of the benthic organisms have not changed appreciably over the period of 1975-1978, since publication of the report to the U.S. Army Corps of Engineers (AHF, 1976), the principal trends have been a large decrease in population sizes, especially of the more abundant species, and a decline in number of species.

There was a slight trend towards increased species diversity at all stations in 1975-76. However, this may have been an artifact of multiple sampling done then, and to crustacean taxonomic studies that increased identifications. These were, therefore, restricted in the computer analyses herein. The numbers of species declined steadily from March 1977 through October 1978.

By October 1978, samples showed faunal changes at both A1 (outside the harbor) and A7 (in the outfall area). Since benthic worms are a principal food for bottom fish, other fish, crustaceans and birds, a large population decrease would have significant effects on those species. The drop in predator populations did not produce increased diversity or populations.

Microbiological cycling of Nutrients

Investigations of microheterotrophs in outer Los Angeles Harbor and in adjacent waters showed that the monthly average was about 2.5 times more bacterial standing stock inside the harbor than occurred outside the harbor, after full secondary waste treatment of cannery and TITP wastes began. The cells collected inside the harbor were also somewhat larger than those collected outside. There was a 30-fold drop in total bacteria following full secondary treatment. The exception occurred during TITP malfunction, which caused a 10-fold increase in bacteria in June-October 1978.

Annual variations in population density of bacteria included two peak periods, one in late spring and one in early fall. These peaks either coincided with or followed phytoplankton blooms closely.

Investigations of the utilization of the bacteria as food sources for marine organisms were conducted, using radioactively labeled bacteria and a marine ciliate, both isolated from harbor waters and cultured in the laboratory. Similar studies were also carried out using species of marine invertebrates that are common in the harbor, including a polychaete and two bivalves. These studies showed that the ingested bacteria were utilized anabolically and as a respiratory substrate. In a situation where the bacterial population was non-limiting, the quantity ingested was dependent on the number of organisms feeding on them. Studies using natural populations of bactivorous plankton collected from a series of stations in the harbor showed that consumption of bacteria varied with the concentration of bacteria. This suggests that the reductions in bacterial population as a result of the changes in the waste discharges in the harbor have removed an important food resource for the fauna of the harbor.

The bacterioplankton rather than phytoplankton were found to be the predominant organisms involved in orthophosphate uptake in Los Angeles Harbor. Studies of turnover time both in and outside the harbor suggest that phosphate is not a limiting nutrient for the bacterioplankton, a conclusion reached earlier for the phytoplankton. The bacteria within the harbor were also found to be generally more metabolically active and less variable than those outside the harbor in their uptake of phosphate.

Common organic phosphate compounds of great biological significance are the adenylates. These compounds occur in nature only as a result of loss from living cells and can be absorbed and used by bacteria and phytoplankton.

Investigations of the uptake of these compounds from harbor waters again indicated that the role of bacterioplankton was predominant over that of the phytoplankton, except prior to a bloom when uptake by phytoplankton increased sharply.

Biostimulation and Growth (Bioenhancement)

Experiments testing selected organisms on various levels of TITP and cannery wastes were carried out to delineate more clearly the specific roles of the wastes in the ecological system described from data that the field monitoring developed.

Cultures of various species of phytoplankton were exposed to concentrations of effluent dilutions from the treatment plant, simulating the receiving waters. Exposure to all of the concentrations tested showed enhanced growth rates in the cultures, with the most marked effect being noted at levels above 1%. Extrapolation of these data to field conditions using calculations of the critical length of the diffusing waste field suggest that the zone of enhancement extends only to about 500-1500 meters from the outfall. Field data suggest that this is an overly conservative estimate.

Experimental month-long exposure of mussels at stations located varying distances from the TITP boil reflected the character of wastes as processed in the plant. During a major plant upset, when high levels of suspended solids and BOD were discharged, growth rates of mussels near the discharge were considerably higher than growth rates at a "control" station. Growth occurred at all sites tested.

Laboratory studies of anchovies fed on sludge collected from a cannery DAF unit were carried out. Maximum concentrations of sludge that would stimulate growth were not reached, but linear regression analysis of data on net growth indicated that increased sludge yielded growth that was about equal to that supported with a similar amount of trout chow. The results were statistically significant.

CONCLUSION

The reports on field collections or observations all show perturbations in the data coinciding in time with the sequence of events occurring at the Terminal Island Treatment Plant and localizing around the site of the outfalls. In general, there were net reductions in fish, bacteria and benthic invertebrates as well as reduced bird populations and possible smaller net reductions in phytoplankton and zooplankton following the conversion of the plant to secondary treatment. Further reductions, even more pronounced, ensued following the diversion of the fish cannery effluents into the treatment plant. These parameters showed significant increases during the months when the treatment plant suffered an upset. During this period high levels of suspended solids and BOD were released. Where data are available these showed sharp drops in the populations sampled after the problem at the treatment plant was alleviated. The reappearance of birds and fish during the episode indicates that the harbor is now only an optional feeding area of opportunity for adjacent populations along the coast.

By far the greatest impact, however, appears to have occurred when DAF and other pre-treatment methods were installed in the canneries in 1974-1975. By comparison, the drops concomitant with secondary treatment were of lesser importance.

It is now apparent that the harbor has been converted from the richest and most diverse soft-bottom community on the southern California coast to a less productive environment. The loss of food resources previously contained in the effluents has resulted in large order net reductions of organisms that fed directly or indirectly on the wastes. In brief, the food web that previously existed has been reduced in scope and magnitude by so-called improvements in physical water quality. The bioenhancement which was previously in evidence has dropped greatly; indeed, total removal of wastes would probably eliminate enhancement altogether.

The studies presented here are felt to document the ecological role in the harbor played by the effluents discharged there. When the effluents contain much organic matter, as shown by the BOD and suspended solids levels, biomass and productivity are high. This was the pattern prior to the conversion to secondary treatment and during the plant upset. Low levels of biological productivity and standing stock prevailed during periods when the treatment plant was removing most of the BOD and solids. What was once a highly productive and diverse biological resource has been made much less so.

There is good evidence that the present ecosystem is enhanced by the secondary waste over and above the conditions that would occur if the discharge were to be removed from the harbor. There is no evidence that present wastes are toxic, generally. There is no indication at present that phytoplankton production exceeds consumption, leading to undesirable eutrophication.

The evidence presented includes field observation and collections supplemented with experimental assay under controlled conditions of the role that both the TITP effluent and cannery effluent have played in the development and control of the harbor biota. These studies, including the statistical analyses of the data, strongly support our conclusion that the harbor biota will be enhanced if a regulated level of untreated cannery wastes are discharged into the harbor and that the harbor can once again become a rich and diverse biological habitat of value to commercial, recreational and conservationist interests.

We believe that a return to release of managed levels of cannery wastes into the harbor without secondary treatment of those wastes would create a better nutrient balance in conjunction with secondary TITP wastes, and would be beneficial to the ecology. This might restore the enhanced condition that prevailed prior to full TITP secondary treatment. We feel that there are too many concomitant drops in a wide variety of taxa and biological processes to attribute all of them to coincidence. Differences between harbor fluctuations and ocean fluctuations can be seen, which coincide in time with waste treatment events in the harbor.

The cannery wastes were not toxic in the same sense that metals and chlorinated hydrocarbons are toxic; high nutrient wastes do require more even distribution in the environment, however. Cannery wastes are very different from some toxic wastes in that they cannot be concentrated in tissues, nor bioamplified by passage through several consumers, as some heavy metals and toxic substances are concentrated.

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BIOENHANCEMENT: CAN THIS CONCEPT BE DEFINED AND MEASURED?

INTRODUCTION

In the years since the passage of the National Environmental Policy Act (NEPA), the National Pollutant Discharge Elimination System (NPDES), and the 1972 revisions to the Federal Water Pollution Control Act (FWPCA), the emphasis has shifted from chemical, physical and biological standards for receiving water quality to the more easily regulated standards for effluent discharges. Apparently the basic impetus, in addition to ease and uniformity of enforcement, was that some particular number, or set of numbers, could be selected as standards that would guarantee good water quality, nationwide.

The Environmental Protection Agency (EPA) delegated to the states the authority to enforce national water quality standards and to develop policies that serve to implement control. Thus the California Resources Agency created the State Water Resources Control Board and the several Regional Water Quality Control Boards (RWQCB).

In May 1974 the policy document, under which Los Angeles Harbor is regulated, was created.

Bays and Estuaries Policy

In the document Water Quality Control Policy for the Enclosed Bays and Estuaries of California (May 1974), the following excerpts are germane to the concept of bioenhancement:

> The Introduction (p. 1) of the above document states that the purpose of the policy is ... "to prevent water quality degradation and to protect the beneficial uses of enclosed bays and estuaries."
>
> In Chapter 1, Item A (p. 2) states that it is the policy of the State Board that discharge of municipal wastewaters and industrial process waters ... "shall be phased out" ... (except) "when the Regional Board finds that the wastewater in question ... *would enhance the quality of receiving waters above that which would occur in the absence of the discharge*."[3] (author's italics)
>
> Footnote[3] (p.11) provides for 96 hour bioassay tests of undiluted effluent such that the effluent would produce not less than 90 percent survival, 50 percent of the time, and not less than 70 percent survival, 10 percent of the time. The footnote continues by indicating that these requirements by themselves *do not constitute evidence*

> "that the discharge satisfies the criteria of enhancing the quality of the receiving waters above that which occur in the absence of the discharge." *This constitutes the principal difficulty of the document; namely, that no definition of enhancement is provided.*
>
> Chapter I, Item B, 1c (p. 3) states that "Monitoring requirements shall be established to evaluate any effects on water quality, particularly changes in species diversity and abundance ..."
>
> This clearly suggests a *biological* evaluation of water quality.
>
> Chapter IV, Item C (p. 9) states that "The Clean Water Grants Program shall require that the environmental impact report for any existing or proposed wastewater discharge ... shall evaluate *whether or not the discharge would enhance the quality of receiving waters above that which would occur in the absence of the discharge.*" (author's italics)
>
> Again, no definition of enhancement is given.

Definition for the City of Arcata

In October 1974, Bill B. Dendy (then Executive Officer of the State Water Resources Control Board) wrote a memorandum to David C. Joseph, Executive Officer of the North Coast RWQCB with the subject titled: Definition of "enhancement" for the City of Arcata (California). Mr. Roger A. Storey, City Manager of Arcata, had requested a definition of the term "enhancement" along with specific criteria for demonstrating that a particular effluent would meet the definition.

Mr. Dendy's letter has been widely circulated in California in an attempt to define the policy, but to date little progress has been made in qualifying any effluent under this "definition." Mr. Dendy's letter is quoted as follows:

> "Before discussing these items, I should point out that the rationale for the establishment of the enhancement concept was provided to State Board members prior to their adoption of the poilcy. This rationale is to be found in pages 5-6 of Appendix A to the Bays and Estuaries Policy.
>
> "My understanding of the term enhancement as it appears in the Bays and Estuaries Policy includes: (1) full uninterrupted protection of all beneficial uses which could be made of the receiving water body in the absence of all point source waste discharges *along with* (2) a demonstration by the applicant that the discharge, through the creation of new beneficial uses or a fuller realization,

enhances water quality for those beneficial uses which could be made of the receiving water in the absence of all point source waste discharges. In short, the Bays and Estuaries Policy requires that a discharge not only provide full protection of beneficial uses which the receiving water body is capable of supporting but also yield a positive water quality benefit.

"In view of the Regional Board's detailed knowledge of particular waste discharges, it was our opinion that it would be the appropriate agency to develop specific criteria which would guarantee full protection of beneficial uses. In approaching this task you may wish to consult EPA's Water Quality Criteria, the State Board's Ocean Plan and the Health & Safety Code which identify waste constituent limits which are appropriate to the problem of protecting the beneficial uses of saline waters. In addition, Footnote 3 of the Policy provides additional guidance with respect to minimum toxicity control and effluent quality guarantees.

"While I believe that your staff could develop effluent limits which reflect what is necessary to protect beneficial uses, I also believe that it is the responsibility of the City of Arcata to provide a convincing demonstration that an identifiable water quality benefit would be realized through the continuation of in-bay disposal.

"I would suggest that as a means of resolving the Arcata issue you request the City to submit a report containing the following information:

a. Identification of those beneficial uses which they contend would be enhanced by the continuation of in-bay disposal;

b. Identification of those effluent characteristics (physical, chemical or biological) which would have a direct bearing on the beneficial uses identified in 2.a. above;

c. Information supporting the contention that receiving water conditions would not be optimum for supporting beneficial uses in the absence of all point discharges, and receiving water conditions the applicant contends would be enhanced by the effluent;

d. Proposed specific effluent characteristics which the discharger believes would enhance receiving water conditions;

e. A description of treatment facilities and cost thereof which would meet conditions identified in item 2.d.;

f. A description of alternatives and costs thereof, which would not involve in-bay disposal (items (e) and (f) should be coordinated with Division of Water Quality).

"I would then suggest that a public hearing be noticed indicating that the information provided by the applicant is on file at the Regional Board for review by interested parties. The purpose of the hearing would be to determine whether in-bay disposal should be allowed to continue based on the following considerations:

1. That there is a beneficial use which could be created or enhanced.
2. That the effluent limits proposed by the applicant would optimize conditions for the realization of the beneficial uses identified in item 1.
3. That continuation of in-bay disposal would not compromise any beneficial uses which could be made of the receiving water in the absence of any point source waste discharge.
4. That the benefits derived from a project meeting conditions one through three above, are commensurate with the incremental costs, if any, of such a project over and above alternatives which did not involve in-bay disposal.

"I believe the requirements of the Bays and Estuaries Policy would be satisfied only if these four conditions were upheld."

It should be noted that Dendy's statement appears to go beyond Footnote 3 in the Policy, which requires bioassay survival tests on a *percentage* basis, whereas he stipulates "uninterrupted protection." This has in some quarters been interpreted to negate the percent survival tests, and to mean *continuous* enhancement.

Along with enforcement of percentages of time for effluents to meet standards, it seems desirable that, in semi-enclosed bays and harbors, some averaging conditions should be allowed over space. This would permit overall enhancement conditions to be evaluated, even if conditions were not as good at the point source, as would be the case at the point of discharge of fresh water into a fully marine environment.

If the general trend of the Arcata letter is followed, it becomes necessary to define two different terms: beneficial uses and enhancement.

Beneficial Uses of Harbor Waters

The application of the term "beneficial uses" has frequently been based only on human orientations; *e.g.*, the uses of harbors for commerce, transportation and industry, or recreational fisheries, body contact sports or boating.

In the Los Angeles-Long Beach Harbors, which are political jurisdictions that divide one body of water into two ports, the emphasis of the beneficial uses has changed in some ten years to reflect the concern for living marine resources as such, as well as for human activities.

An example of this sequence can be seen in documents dating from 1969 to 1978, described below.

In May 1969 the Los Angeles RWQCB listed in a review document the nine main uses of harbor waters at that time, as follows:

A. Shipping
B. Anchorage
C. Waste disposal
D. Recreation
E. Fishing
F. Dry docks
G. Cooling water
H. Air washing
I. Food handling

The document noted that the Board had enunciated the following major beneficial uses of harbor waters to be protected:

Outer Harbor Area

Shipping
Yacht anchorage
Bait fishing
Bathing, recreation and sport fishing

No mention of natural biological environment was made, except as it pertains to resources for man.

In July 1972 the State WRCB adopted Resolution No. 72-45 entitled "Water Quality Control Plan for Ocean Waters of California." It gave the beneficial uses of ocean waters in general to include... "industrial water supply, recreation, esthetic enjoyment, navigation, and preservation and *enhancement of fish, wildlife, and other marine resources or preserves*." (author's italics). It further stated (Chapter IID) that "marine communities, including vertebrate, invertebrate, and plant species, shall not be degraded."

Coupled with the Bays and Estuaries Policy of May 1974, referred to previously, this is representative of the State position on beneficial uses and protection of ocean waters in general, and harbor water in particular.

In June 1978 the Port of Long Beach was the first in the

State to have a Final Master Plan accepted by the California Coastal Commission. In the section on goals and objectives the first item is as follows:

> "1. The Port will seek to protect, maintain, *enhance* and restore the overall quality of the coastal environment, its natural as well as man-made resources ...
>
> ...--Preserve existing fish nursery areas and indigenous water habitats.
>
> -- Maintain significant natural habitats which exist in the Port."

Other beneficial uses of the harbor that have been suggested recently include mariculture. Some pilot projects have been proposed for use of Los Angeles-Long Beach Harbors waters, and test have been made using pretreated cannery wastes and TITP wastes.

Enhancement and Bioenhancement

Enhancement is the improvement of some particular parameter or set of parameters according to the value system of a participant or observer.

Bioenhancement refers to a more specific set of parameters, namely to diverse organisms and their habitats. The term bioenhancement is sometimes applied according to the immediate perspectives or values of humans, such as fisheries resources for food or recreation. However, in the context of environmental quality, it should be applied as though organisms also had intrinsic values not dependent upon human value systems.

Because enhancement is the more general term, it can be applied to parameters, valued by humans, that are almost mutually exclusive to the intrinsic biological system. For example, completely clear water may be esthetically pleasing to seashore visitors and boaters. However, to plants and animals completely "clean," clear water represents an environment devoid of food.

Enhancement of water quality is viewed by regulatory and enforcement agencies as achievement of a given set of numerical values of such parameters as dissolved oxygen, pH, temperature, transparency and absence of chemicals or bacteria. Such "enhancement" may lose sight of the fact that protection of diverse organisms is one of the basic reasons for environmental quality legislation in the first place.

The major humanistic objectives of esthetically pleasing, potable, swimmable fresh water may possibly be achieved only by having chlorinated water, reduced in nutrient content. Under these conditions, such as occur in some rivers and lakes, human value criteria are applied which make a positive choice for the needs of people for safe drinking water as opposed to organisms or habitat. The intrinsic biological values are secondary or are selected against. It therefore seems apparent that enhancement of water quality could occur while enhancement of biological quality, or bioenhancement, is being degraded or eliminated. Thus it is essential to develop criteria by which true biological enhancement can be defined.

Criteria for Evaluating Biological Enhancement

In May 1978, a California legislator requested suggestions for text that might be added to the California Bays and Estuaries Policy to define and evaluate bioenhancement. The following statement was submitted by the present principal investigator as a suggestion for further discussion and development:

> "The criteria for evaluation of enhancement shall include, but not necessarily be limited to: species diversity, and/or the presence of species with commercial and/or recreational value, and/or the presence of rare, endangered or threatened species, and/or the presence of living biomass, above that which would occur in the absence of the discharge."

Additions to the above criteria could well include species richness, presence and interaction of essential food web species, ecological diversity, or population dynamics measurements. *It should be recognized that no single criterion shall be considered sufficient to qualify as bioenhancement, but a combination of two or more might be utilized.* There are cogent reasons for not accepting one criterion alone. The inherent complexity of biological systems leaves each parameter, or the methods for measuring it, open to criticism. Also the systems are subject to development of new criteria, or new quantification techniques.

The utilization of at least two criteria would provide some assurance that the drawbacks of any given method of evaluation did not bias the conclusions unduly. The consensus of the scientists consulted by the present investigators was that bioenhancement can be defined by criteria that are quantifiable, although the biological measurements are less precise than those of physical and chemical systems.

DISCUSSION

The two sorts of bioenhancement referred to previously -- that which benefits man and that which benefits the biota with intrinsic value -- deserve further discussion. By developing criteria for evaluation it should become possible to designate the biological quality of specific areas or effluents. Quantifying biological organisms is generally not difficult, but evaluating species or communities quantitatively is far more difficult and subject to controversy than is quantifying and evaluating physical parameters. It must be remembered, however, that selection of regulatory levels for physical parameters is not an end in itself but represents an attempt to protect biological systems supported by the physical conditions.

Human Values and Intrinsic Values. Societal values for the marine biological environment are generally represented by commercially valuable species, primarily those that are prized for food, or by environments that are esthetically pleasing, such as the biologically diverse seashore.

Man tends also to value predator species at the top consumer level of the food energy cycle that actually compete with man for food; these species include whales, dolphins and sea lions as well as pelicans and other birds. It is only in relatively recent years that a portion of society has voiced the principle that worms or algae have sufficient intrinsic environmental value to deserve protection from environmental insult or outright destruction.

The commercially valuable species are readily recognized, but understanding the species, community and habitat on which the commercial species depend is difficult at best and oftentimes impossible. Illustrative of this are the difficulties in developing the federally mandated Fish Management Plans (FMP). In order to develop harvest quotas, the sustainable yields have to be calculated from knowledge of reproductive cycles, habitats and ranges and food requirements. Yet very little information could be found for some commercial species. The conservative approach to protection and enhancement thus must be that all species in a habitat may be important to some commercial crop and should therefore be valued. At this point the commercial interests merge with the intrinsic valuation of all species, but for different reasons.

Species Diversity. Several species diversity indices have been developed over the years; the Shannon-Wiener is perhaps one of the most widely used. One problem with the species diversity criterion is that diversity might be low because of man-made abuses of an area, or it might be low due to the limitations of the natural habitat. For example, where estuarine flow is intermittent, as it is in Los Angeles where rainfall is limited to a few major winter storms, the salinity changes are too rapid and too severe to be tolerated by anything except hardy, euryhaline species. Storm flow in some regions may be so strong that most plankton and nekton are carried to sea. Recolonization occurs regularly, but diversity may be very low in relation to biomass because only opportunistic species will be present shortly after the storm season. Yet there is evidence that such changes create better estuarine conditions than would stable conditions which allow a few species to dominate a community permanently. The literature is extensive on the relative merits of various methods for measuring diversity. Total numbers of species alone are often as revealing as complex calculations, however.

Presence of Species with Commercial or Recreational Value. It is easy to identify areas where commercial or recreational fisheries exist. Not so easily identified are areas that serve as spawning grounds, as juvenile nurseries, or as sources of food chain organisms essential to the large predator species of fish or shellfish. Often these elements are unknown, poorly known, or ignored.

Of particular importance is the support of the phytoplankton crops, which are the primary producers of energy (food) for so many of the marine consumer and predator organisms. Bacteria and protistans are also essential to food webs as food sources for certain invertebrates (filter feeders), and as primary agents of nutrient recycling. Yet the public, incorrectly, associates bacteria almost exclusively with terrestrial disease.

Rare, Endangered or Threatened Species. Just as is the case with the easily identified commercial species, the rare and endangered species have largely been recognized. However, the needs of the latter species may be even less well known than the food chain and habitat requirements of commercial species. Threatened species may not be recognized as such when they are a few steps from the endangered or rare classification. The turning point may be when a population decreases until it is too scattered to breed *en masse*, even though substantial numbers of animals still exist. So many factors are unknown, that it is essential to give close attention to those factors which can be identified as to species and populations.

A case in point is the Northern Anchovy, which has declined drastically off southern California since 1975. Is the decline due to a change in eastern Pacific water temperatures; is it due to intensive commercial fishing in a few areas, which separated the large breeding populations; or it it due to a reduction in terrestrial nutrient flows which have in turn reduced phytoplankton and zooplankton densities in inshore waters, densities on which the tiny larvae depend? Or it it due to a combination of these or other, unidentified factors?

A parenthetical question may be asked as to why nutrients of terrigenous origin that are digested aerobically and anaerobically in deep canyons in the ocean and then brought to the surface by upwelling are considered "good," while the same kinds of nutrients delivered from outfalls are considered "bad." At the present time very costly experiments are simulating upwelling offshore by pumping nutrients up from deep canyons to nourish transplanted kelp beds off the southern California coast, for potential methane production when harvested. Yet non-toxic nutrient wastes are being regarded as hazardous to the environment and subjected to expensive secondary waste treatment requiring land disposal of sludge.

Biomass. Biomass is a valuable, quick indicator of the presence and quantity of life in a given locality, but since the measurement gives no hint of the quality of living material, size of individual organisms or identifiable ecological role, the criterion taken alone is not a good one. In stressed environments it has long been recognized that large numbers or weights of one or a few species that are extremely tolerant, opportunistic or rapid reproducers, may be present. The lack of diversity is considered to be a fault -- unless, of course, that biomass happens to represent clams or oyster beds!

Richness. While the usual species diversity indices consider both numbers of species and numbers of individuals, richness emphasizes numbers of species. Habitat diversity is generally essential to species diversity because of the variety of microenvironments it provides. Thus, for example, a silty-bottomed estuary with unconsolidated sediments eliminates many invertebrates that require solid substrate or cannot tolerate turbid, silty water. Such a soft bottom is, however, ideal for filter-feeding worms and the flatfish that feed on them. Also, measurement of habitat diversity according to species diversity might suggest to some that rocky shore intertidal habitats were the best and that soft-bottomed bays and estuaries should therefore be considered undesirable.

Evenness. In some instances, species diversity may be high, but only one or a few species may provide a very large percentage of the individuals. This is considered to be less desirable than a more even distribution of numbers among the species or among the higher taxa present.

While some of these points may seem obvious, it should be clear that there are several criteria that can be selected to evaluate for determination of biological enhancement. There are numerous references on methods now available for quantifications (Pielou, 1975; Smith, 1978; see also section IVC in this report). Entire journals are devoted to ecological measurement and evaluation; certainly these resources offer tools for quantifying bioenhancement.

EVALUATION OF BIOENHANCEMENT IN OUTER LOS ANGELES HARBOR

PREVIOUS STUDIES

In December 1976, in a publication entitled "Bioenhancement Studies of the Receiving Waters of Outer Los Angeles Harbor (Soule and Oguri, 1976) summary statements were made based on five years of field and laboratory research, and particularly on the harbor-wide intensive field studies of 1973-1974 for the U.S. Army Corps of Engineers (AHF, 1976). The following excerpts are from the bioenhancement study of 1976:

> "Physical conditions surveyed include circulation and flushing, temperature, dissolved oxygen, pH, salinity, turbidity, sediment character, pollutants, BOD and nutrients. Biological parameters include microbiology, phytoplankton productivity, zooplankton, benthic and water column invertebrates, fish and birds.
>
> "Laboratory studies have been carried out on bioassays, reproduction and growth, stress, toxicity, and food web relationships.
>
> "Mathematical modelling studies use the baseline data to relate the parameters to one another and work toward projection of organic loading in relation to assimilation capacity of the receiving waters.
>
> "The following statements summarize the information and conclusions derived from these investigations.
>
> "1. The field studies indicate that the present state of the harbor is healthy. Rich and diverse biotic elements are supported by the present environmental regime. Episodes of stress, which occurred in earlier years, as indicated by reduced levels of dissolved oxygen, have not been noted since the canneries have instituted improved waste management procedures.
>
> "2. Bioenhancement (the enhancement of the biological quality of receiving waters) is occurring in outer Los Angeles Harbor, due at least in part to the presence of natural waste effluents.
>
> "3. Bioenhancement has been evaluated in terms of numbers of organisms and species diversity of

plankton, benthic organisms, and standing crop of fish, as well as in biomass and a number of other factors detailed in the research reports.

"4. The fish populations are higher in the outer harbor than in any other local coastal soft bottom area in southern California. The harbor is an essential nursery grounds for the 0-1 year age class of anchovy and for other fish species.

"5. Under present conditions, a small zone within approximately 200 feet of the outfalls exists where numbers of species are low. Adjacent to this zone is a zone of enrichment which extends through most of the outer harbor. Beyond that, conditions return to average coastal populations. The regulation of waste loading and control of pollutants in the past six-year period has brought the harbor ecosystem from a depauperate biota to a moderately rich one in the immediate outfalls zone, with a very rich biota in the adjacent outer harbor area.

"6. There is a net bioenhancement over and above those conditions which would occur in the absence of the existing natural waste discharges.

"7. Cessation of all effluents would probably cause a gradual or accelerated reduction in the biota and ecosystem. Such phenomena have been documented in the United States and elsewhere; e.g., the Aswan Dam has caused a severe reduction in the Mediterranean fisheries.

"8. Management strategies can be developed to predict generally the amount of loading possible under various environmental conditions. Mathematical model studies of the harbor based on the data being collected, suggest that the assimilation capacity of the receiving waters is not being exceeded by the organic load discharged in these waters. The model studies are being further developed to reflect short-term stress and change.

"9. A more limited biota, tolerant to the effluents, is found in a relatively small area near the discharge points. Harbor organisms more sensitive to the effects of the effluent are not usually found there and on laboratory

> testing are unable to survive in high concentrations of the effluent."

It should be emphasized that the following criteria have been and will continue to be used in evaluating the 1977-78 studies of the harbor:

- Species diversity of planktonic and benthic invertebrates, and of fish and marine-associated birds.
- Numbers of individuals of diverse species and also of higher taxa (evenness; hierarchical diversity).
- Total numbers of organisms of diverse taxa (richness).
- Biomass, standing crop or standing stock of all species, by weight.
- Presence and interactions of essential food web species where known.
- Presence of species of commercial or recreational value.
- Presence of rare, endangered or threatened species.
- Potential for mariculture, either in-harbor or out-harbor.

While the Los Angeles Regional Water Quality Control Board agreed that bioenhancement had been demonstrated and ordered continuation of cannery waste discharge permits, others, including EPA Region IX staff, felt that bioenhancement had not been demonstrated. Cannery effluents were diverted into the Terminal Island Treatment Plant (TITP) between October 1977 and January 1978, after TITP was converted to secondary waste treatment in April 1977.

Criticism of the evidence for bioenhancement was partly based on the empirical, or circumstantial, nature of the data. A few persons disagreed about whether most of the outer harbor was a rich, soft-bottom community. However, others who agreed that it was rich, felt that there was no evidence that the cannery and/or TITP wastes were related to or responsible, at least in part, for that richness.

NEW INVESTIGATIONS

Field Investigations and Data Analysis. The City of Los Angeles had need of data for an Environmental Impact Report (EIR) on the relocation and construction of a new TITP outfall, as well as for data for the State and Regional Water Quality Control Board (WQCB) regarding any impact of the secondary TITP waste on the environment. Therefore, a new monitoring study was undertaken using most of the same parameters studied previously (see Table 1). Computer and other analyses of the field data give a means of comparing the harbor under the following estimated conditions and times:

1971-74	Prior to Dissolved Air Flotation (DAF) pre-treatment of cannery wastes; urban primary TITP wastes
1975-77	DAF treated cannery wastes; primary TITP wastes
Apr-Oct 77	DAF cannery wastes; secondary TITP effluent
Oct 77-Jan 78	Canneries hook up to TITP; secondary TITP effluent
Jan-May 78	Variable secondary TITP (Chlorination Mar 9-Aug 30, 78)
Mar 9-Aug 30, 78	Chlorination of TITP
June-Aug 78	TITP upset, primary plus suspended solids
Sept-Dec 78	Secondary TITP

These data analyses show some "coincidental" trends. However, there are no "control" harbors, available for use in ecological studies, in the fashion of laboratory sciences. This requires that the studies make comparisons of biological parameters in time, and in space, by virtue of distances from the effluent, and differences in substrate, circulation patterns or other physical parameters.

Experimental Evidence. Another area that was considered open to criticism was a lack of sufficient evidence in 1976 for uptake and energy cycling at the biochemical and microheterotrophical levels. Extensive experiments have now been carried out on uptake kinetics of relevant substances crucial to the trophic structure.

Bioassay studies have continued to utilize various invertebrates and vertebrate species typical of harbor waters to check for toxicity or biostimulation due to the TITP effluent. The

1977 EPA/Corps of Engineers regulations for ocean dumping of dredge material fully vindicated our practice of using relevant harbor invertebrate and vertebrate species (to which EPA Region IX objected in 1976) rather than the Standard Methods approach with killifish as test organisms.

Bioassay of cannery wastes was repeated and was followed by feeding experiments with liquid and solid wastes to determine comparative growth rates.

Results and conclusions from the various studies led to a number of important observations and conclusions which are presented in subsequent sections of this report.

Figures 1-4 show the locale and survey stations of the study area. Figure 1 is the southern California bight near Los Angeles and Figure 2 shows the changes in the harbor from 1872-1972. Figure 3 is of the field survey stations for 1978. Most of the same stations were monitored in 1973 and 1974 (AHF, 1976). Figure 4 is of the 1972-78 effluent monitoring stations, which were sampled to meet RWQCB effluent permit requirements for the canneries (Series 1A-4A), and stations monitored for Pacific Lighting (Series A1-A12).

LITERATURE CITED See Section VI

Table 1. PARAMETERS MEASURED, LOS ANGELES-LONG BEACH HARBORS

A. MONTHLY MONITORING	METHOD
1. Abiotic Parameters	
a. Temperature	Martek electronic remote probe, at 1m intervals through the water column
b. Salinity	
c. Dissolved Oxygen	
d. pH	
e. Light transmittance	Hydroproducts Transmissometer, remote probe with self-contained light path, at 1m intervals through depth
f. Ammonia	Solorzano (1969)
g. Nitrite	Strickland and Parsons (1968)
h. Nitrate	Modified Strickland and Parsons (AHF, 1976)
i. Phosphate	
2. Biotic Parameters	
a. Biological Oxygen Demand (BOD)	Standard Methods (American Public Health, 1971) modified by Juge and Greist (1975), surface samples
b. Total Coliforms	Millepore (1972), AHF (1976)
c. Fecal Coliforms	
d. Fecal Streptococcus	
e. Bacterial Standard Plate Count	Amer. Soc. Microbiol. (1957); AHF (1976)
f. Primary Productivity, Phytoplankton	Modified Steeman-Neilsen (1952) ^{14}C light and dark bottles, standard light source incubator with ambient water temperature
g. Chlorophyll	Spectrophotometry, Strickland and Parsons (1968) equations
h. Assimilation ratio	
i. Zooplankton species	253u net surface tow with flow meter
j. Water column fouling fauna, larvae and juveniles	Glass microscope slides in wood frame rack, plastic screened, suspended at 3m depth

B. QUARTERLY MONITORING	METHOD
1. Abiotic Parameters	
a. Sediment grain size	Pettijohn (1957), Felix (1969), Gibbs (1971), AHF (1976)
b. Trace metals pesticides	Amer. Publ. Health (1971); AHF (1976)
2. Biotic Parameters	
a. Benthic Fauna	Campbell grab or Reinecke box corer, 0.5mm screen
b. Fish species	Otter trawl, gill netting
C. BIWEEKLY MONITORING (OUTER LOS ANGELES HARBOR ONLY)	
1. Abiotic Parameters	
a. Temperature	Martek electronic remote probe, at 1m intervals through the water column
b. Salinity	
c. Dissolved Oxygen	
d. pH	
e. Oil and Grease	Amer. Publ. Health (1971)
2. Biotic Parameters	
a. BOD	Standard Methods (Amer. Publ. Health, 1971) modified by Juge and Greist (1975), surface samples
D. WEEKLY (OUTER LOS ANGELES-LONG BEACH HARBORS) 1973-1974	
1. Biotic Parameters	
a. Bird census	Observations of nesting, resting, feeding and transit

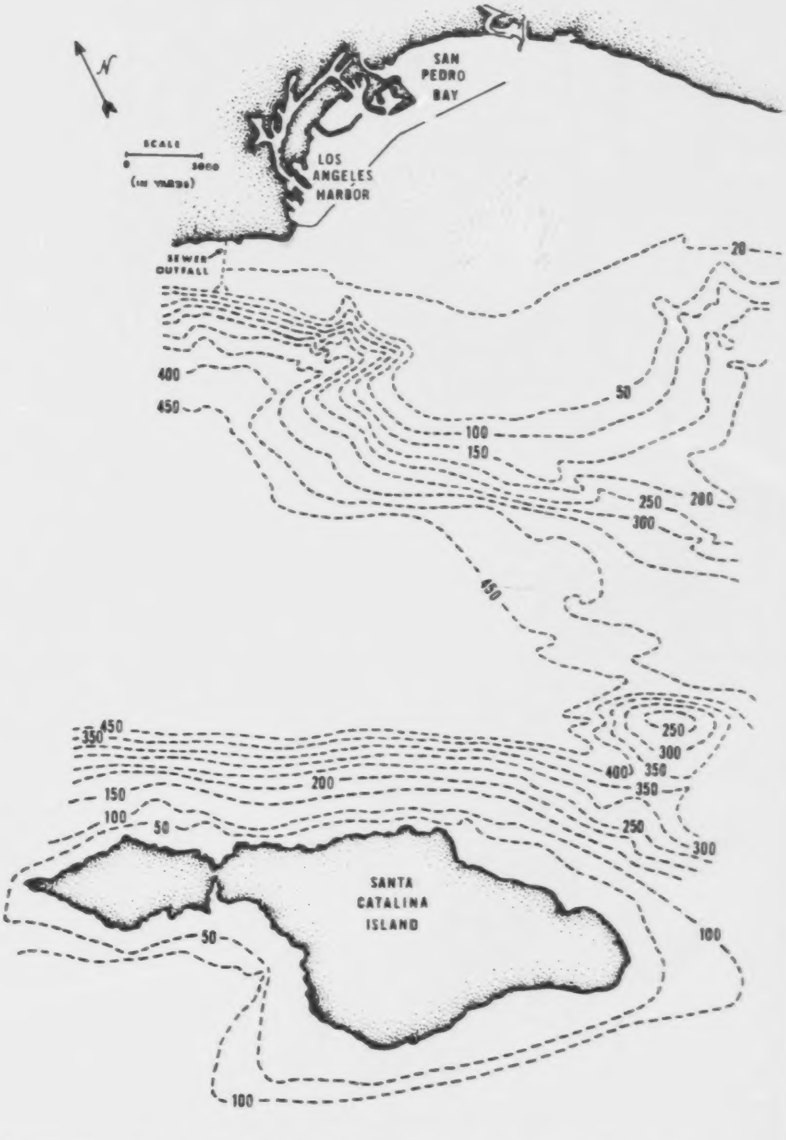
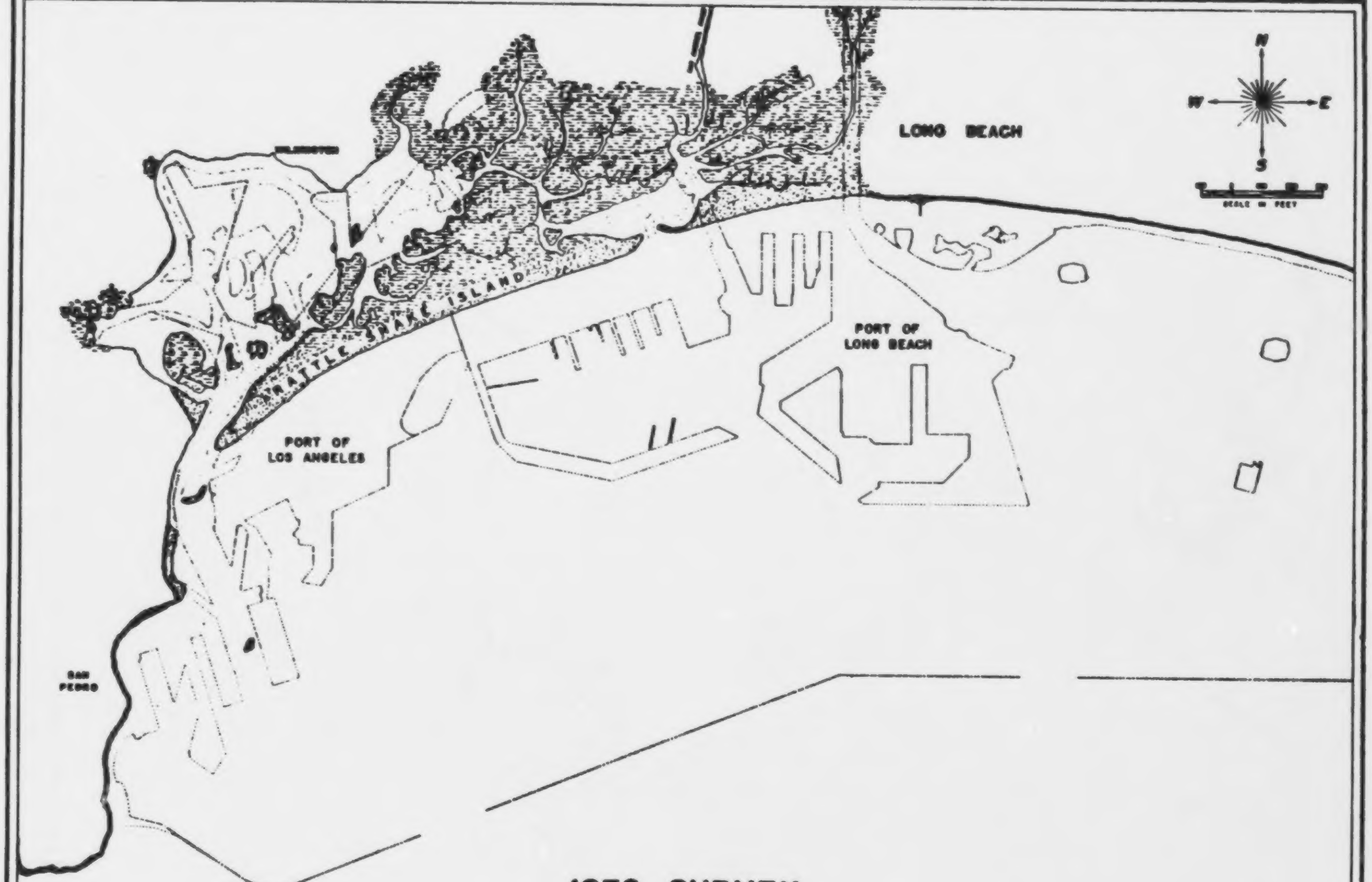


Figure 1. Southern California Bight near Los Angeles.
(contours in fathoms)

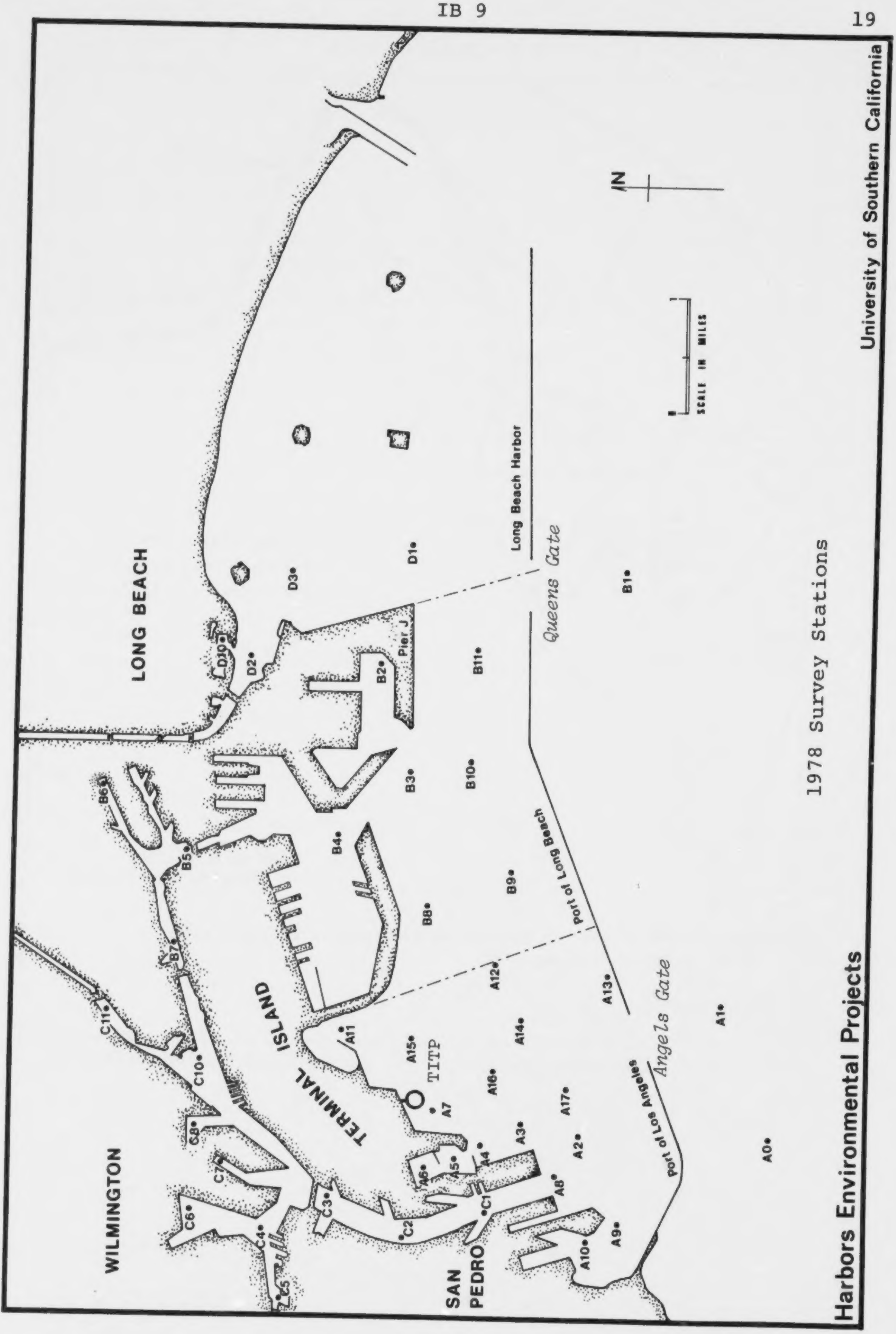


1872 SURVEY

WEST SAN PEDRO BAY SHORELINE

Figure 2

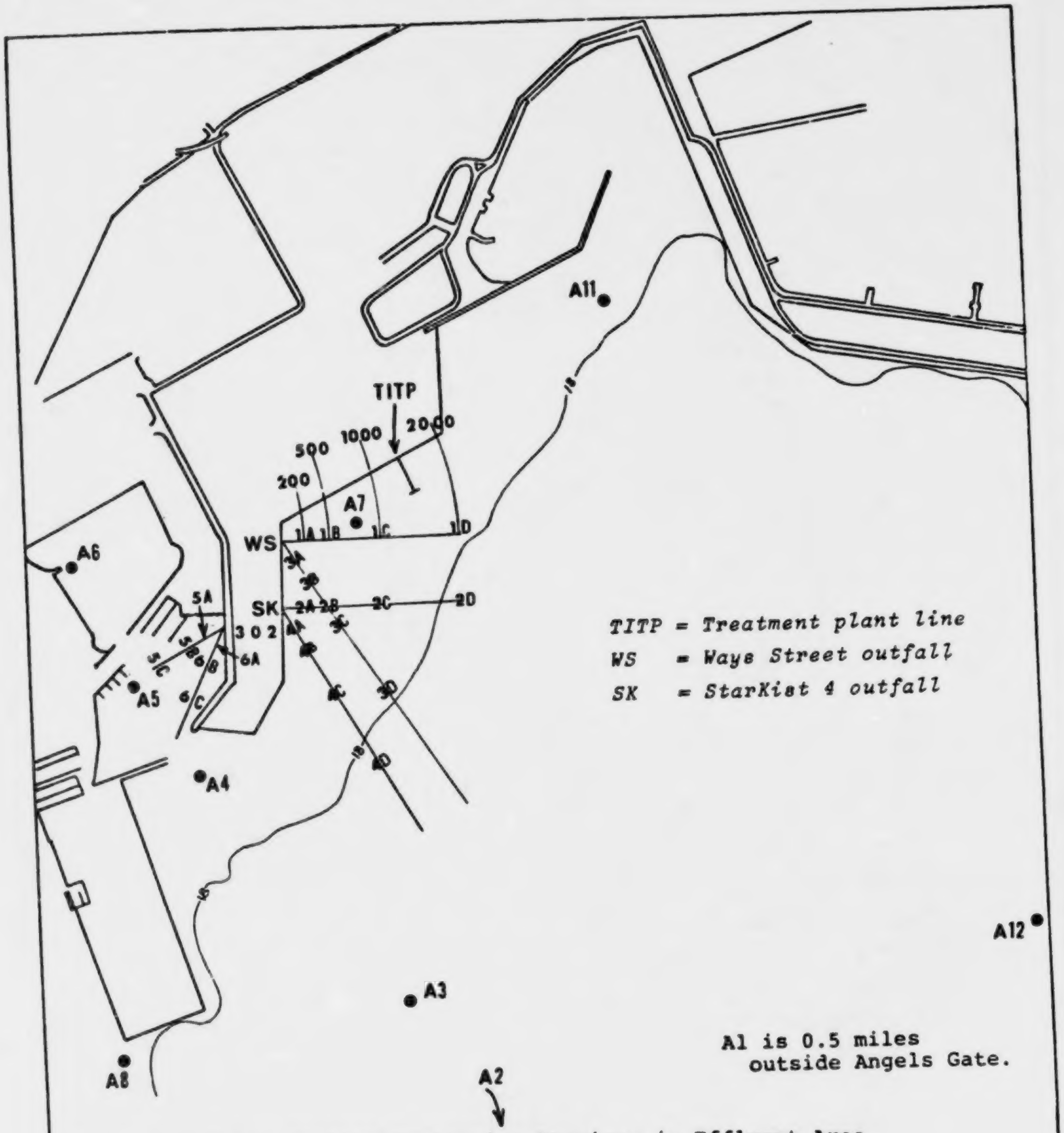
Source: Port of Long Beach General Plan



1978 Survey Stations

Harbors Environmental Projects

University of Southern California



TITP = Treatment plant line
WS = Waye Street outfall
SK = StarKist 4 outfall

A1 is 0.5 miles
outside Angels Gate.

Figure 4. Water Quality Monitoring Stations in Effluent Area May 1972 - May 1978.

CHRONOLOGY OF WASTE EFFLUENT EVENTS IN OUTER LOS ANGELES HARBOR, 1977-1978 AND COASTAL WEATHER

The thesis that wastes in the outer Los Angeles Harbor have contributed substantially to a rich ecosystem following control of toxic substances, solid wastes and excessive oxygen demand effluent loads was discussed previously (Soule and Oguri, 1976). In 1977 and 1978 a number of significant changes were made that may have affected the biota there. Prior to April 1977, the Terminal Island Treatment Plant (TITP) discharged about 10 mgd (million gallons per day) of primary treated wastes into outer Los Angeles Harbor. Two other wastewater outfalls, Way Street and StarKist No. 4, in the vicinity of the TITP effluent line, served as conduits for the discharge of wastes from the three nearby canneries (Figure IB 4) which varied in flow from 2 to perhaps 30 mgd. The effluent from TITP averaged about 200 ppm for BOD and about 100 ppm for suspended solids, as shown in Figure 1, during the first part of 1977.

In April 1977, TITP converted to full secondary treatment, using an activated sludge process. By summer the plant had worked out most of its operational problems and the treatment process had essentially stabilized. Figure 1 illustrates this, showing that BOD and suspended solids dropped to about 10 ppm.

The effluents from the canneries were phased into TITP, starting in October 1977 and being completed in January 1978, with some resultant perturbations in BOD and suspended solids released in the effluent. These are also evident in Figures 1 and 2.

Chlorination was started at TITP for the first time on March 9, 1978. Prior to this only short intermittent periods of chlorine usage occurred as the associated equipment was tested. Chlorination continued until the end of August 1978, when supplies of the chlorine were exhausted. There are no plans to maintain a supply at the plant.

The effluents from the canneries presented several severe problems. The wastes from the canneries were high in salt and very high in organic content, averaging about the salinity of sea water, with an average BOD of about 1000 ppm; both were highly variable, however. The difficulties were compounded by the intermittent nature of the flow. The canneries do not normally work 24 hours a day or 7 days a week. During the year the quality and quantity of the effluent also would vary, depending on what fish were being processed and how much was available for processing.

By forcing the canneries to maintain a controlled or relatively constant flow of sea water, the variations in salinity and flow rate could be compensated for. This approach resulted in a combined flow of cannery, domestic and industrial wastes of about 15 mgd, as shown in Figure 3, except when storm water runoff exceeded TITP design capacity of 30 mgd in March 1977.

In July 1978, a major plant upset resulted in sharp increases in both BOD and suspended solids to levels higher than occurred in 1977 prior to the conversion to secondary treatment. A bloom of filamentous bacteria prevented settlement and removal of solids. An increase in aeration instituted in September 1978 resulted in reduction of BOD and suspended solids to more acceptable levels; however, stabilization of the floc continues to be a problem due to fluctuations in salinity of influents.

Another aspect of the effect of the changes that took place at TITP can be seen in the inorganic nitrogen compounds in the effluent. Under primary treatment, ammonia, a breakdown product of organic nitrogenous compounds, is produced in some quantity. Figure 4 compares this for 1977 and 1978. The concentration of ammonia started falling with the institution of secondary treatment in April 1977 and continued dropping through the summer as the process stabilized. In October 1977, when the first of the cannery effluents entered the plant, the ammonia levels rose sharply. This apparently reflected the high organic content of the cannery waste and may have been responsible for some bioassay mortalities in the fall of 1977. The irregular increases in ammonia content tend to emphasize the difficulties involved in the adjustment of the treatment process to this change. A series of episodes of high ammonia persisted into the summer of 1978, when the major plant upset occurred. This showed high levels of ammonia that finally were sharply reduced by greatly increased aeration introduced in September 1978.

The aeration was apparently instrumental in conversion of the ammonia to other inorganic nitrogen compounds. Figure 5 shows that there is an inverse relationship between ammonia concentration and nitrate. Although not plotted, nitrite shows a curve similar to that of nitrate.

All three forms of nitrogen serve as effective fertilizer salts for the growth of phytoplankton, although there is evidence that ammonia is preferentially used by some species. Ammonia is highly toxic to many animals at relatively moderate concentrations. Its removal from the effluent should, therefore, result in a less toxic environment. However, the conversion of ammonia by marine bacteria, which carry out as much as 50 percent of the initial uptake of nutrients in the harbor (discussed in Section III in this volume), may have been greatly reduced by the 20- to 30-fold decrease in ammonia. This would in turn significantly reduce bacterial biomass as available food for benthic filter feeders and zooplankton, which feed in part on bacteria and on associated particulate organic debris.

Data for the preceding section were largely obtained from the monthly reports on waste discharge at Terminal Island Treatment Plant prepared by the City of Los Angeles Department of Public Works Bureau of Sanitation for the Regional Water Quality Control Board. Note that their measurements are in mg/l, whereas finer detection limits of μg atoms/l are used in HEP research.

Effects on the immediate zone of influence around the outfall of changes in waste treatment were measured by Harbors Environmental Projects (HEP) of the University of Southern California. Stations that were established as part of the monitoring requirements for the fish canneries through the Tuna Research Foundation were utilized to examine nutrient input and zooplankton in a much smaller area of receiving waters (Figure 6). This area had been tested with bioassays of anchovies in 1976 and the area closest to the cannery outfalls (WS and SK) identified as a so-called "zone of mortality" because of the anchovy mortality rates in laboratory tests. No further effluent bioassays were authorized to determine whether this was a transitory or recurring effect, because the canners were ordered by EPA to connect with the TITP system. However, tests of the semi-solid sludge as a fish food are discussed in section V.

Nutrient and plankton samples were taken along transects in August 1977 when TITP had converted to secondary treatment but was somewhat unstable. The cannery outfalls were still in use. Similar samples were taken in October, when SK outfall was being phased out, and in December 1977 and February 1978. Routine Biochemical Oxygen Demand (BOD) samples were taken twice monthly for RWQCB through April 1978.

Figures 7, 8 and 9 present Ammonia-Nitrogen data for August, October and December 1977 respectively. An increase in October is reflected in the scale on Figure 8 and may have coincided with the anchovy season. Ammonia was clearly a product of both canneries and TITP until December, when the second cannery outfall (WS) was being phased out.

Nitrate (Figures 10-12) was associated more with domestic wastes than with the canneries in August, but the pattern was unclear in October. This may have been a very transitory distribution, perhaps due to tidal dispersion. In December it should be noted that nitrate levels had risen greatly, with a maximum of 15 μg at/l rather than 4.5 in the previous two samplings.

The BOD patterns shown in Figures 13-15 give a clear illustration of the enormous drop in nutrients by cessation of the cannery effluents. In August, the three outfalls have about the same BOD, up to 162 mg O_2/l. In October (Figure 14) only the Ways Street outfall (WS) showed significant amounts of BOD (180 mg O_2/l maximum). By February 1978, however (Figure 15), the scale is much reduced and only the two lowest symbols are used (from 4 up to 11 mg O_2/l).

Computer analysis indicated that this series of stations is represented adequately for most parameters by the single station A7 in the regular monitoring discussed in this volume. Tide, gyre and wind effects create mixing that overrides the transitory nature of the finer scale sampling in relation to the rest of the outer harbor. Therefore, the finer scale sampling data are not presented further.

COASTAL WEATHER

No analyses of events within the harbor can be considered without mention of meteorological conditions which effect local storm runoff as well as coastal currents and water temperatures.

Unofficial rainfall records in the foothills of the Los Angeles Basin have been kept for 1972-1978 (J.D. Soule, pers. comm). These are presented in Table 1. Rainfall totals vary throughout the basin, with the foothills receiving more than the central city area. Drainage furnishes a major input to the south coast harbors. Since the usual rainy season is in the winter months, both winter season totals and calendar year totals are given. These data are important to discussions in following sections.

According to Lasker (1978) water along the California coast were about 1°C cooler than normal in December 1977. A warming trend brought warmer-than-normal waters in February and March 1978. Precipitation brought record low salinities in the California current. Mean temperatures were similar to 1977 and 1978 in local ocean waters but the minima were higher in 1978 (Scripps Institute of Oceanography, pers. comm).

LITERATURE CITED See Section VI

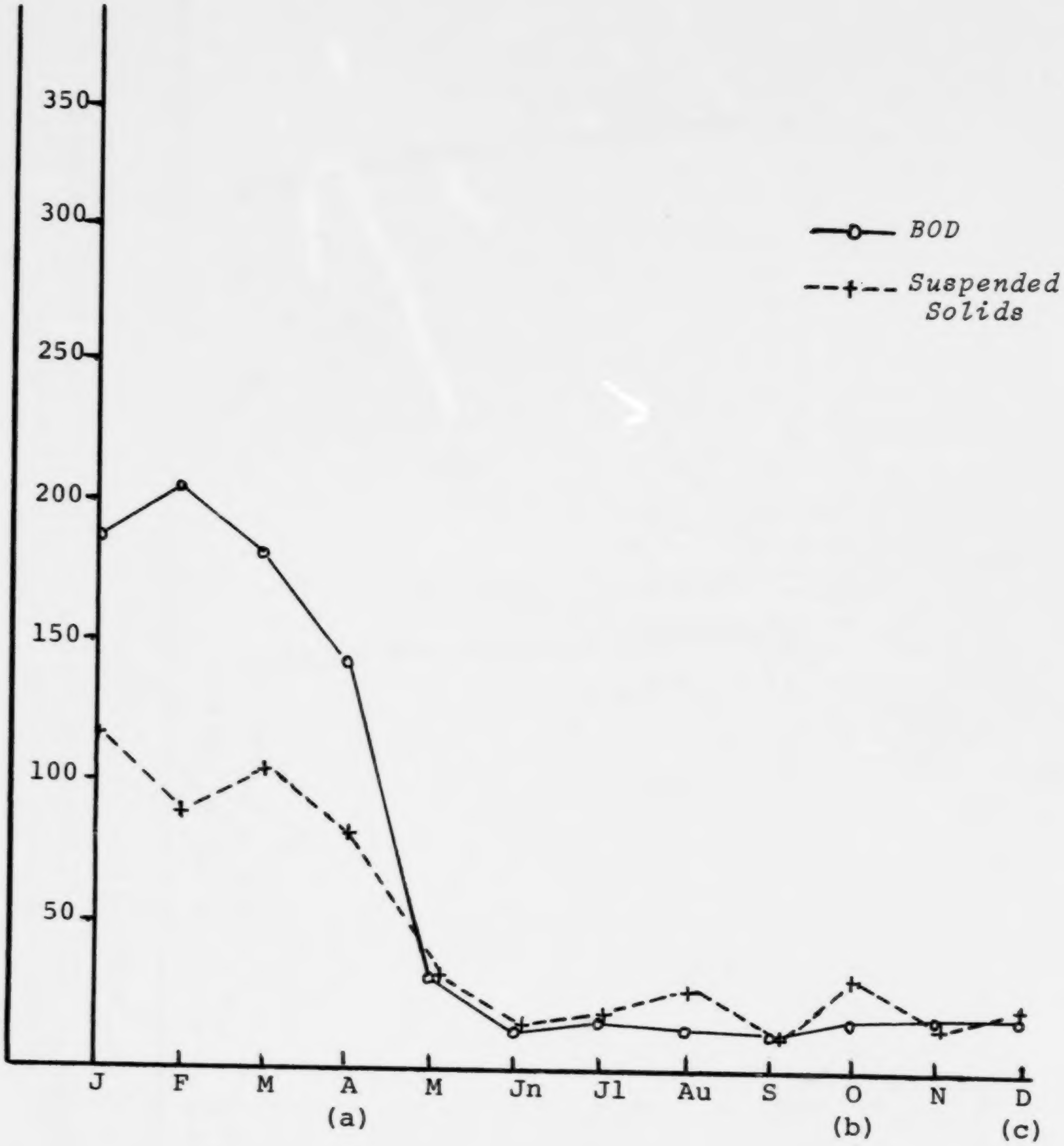


Figure 1. Monthly Mean TITP Effluent BOD and Suspended Solids, 1977 in mg/l.

Notes:
a. first secondary treatment in April
b. first cannery effluent added in October
c. cannery BOD's averaged about 1000 mg/l until October, e.g., in February combined BOD may have averaged 600 mg/l.

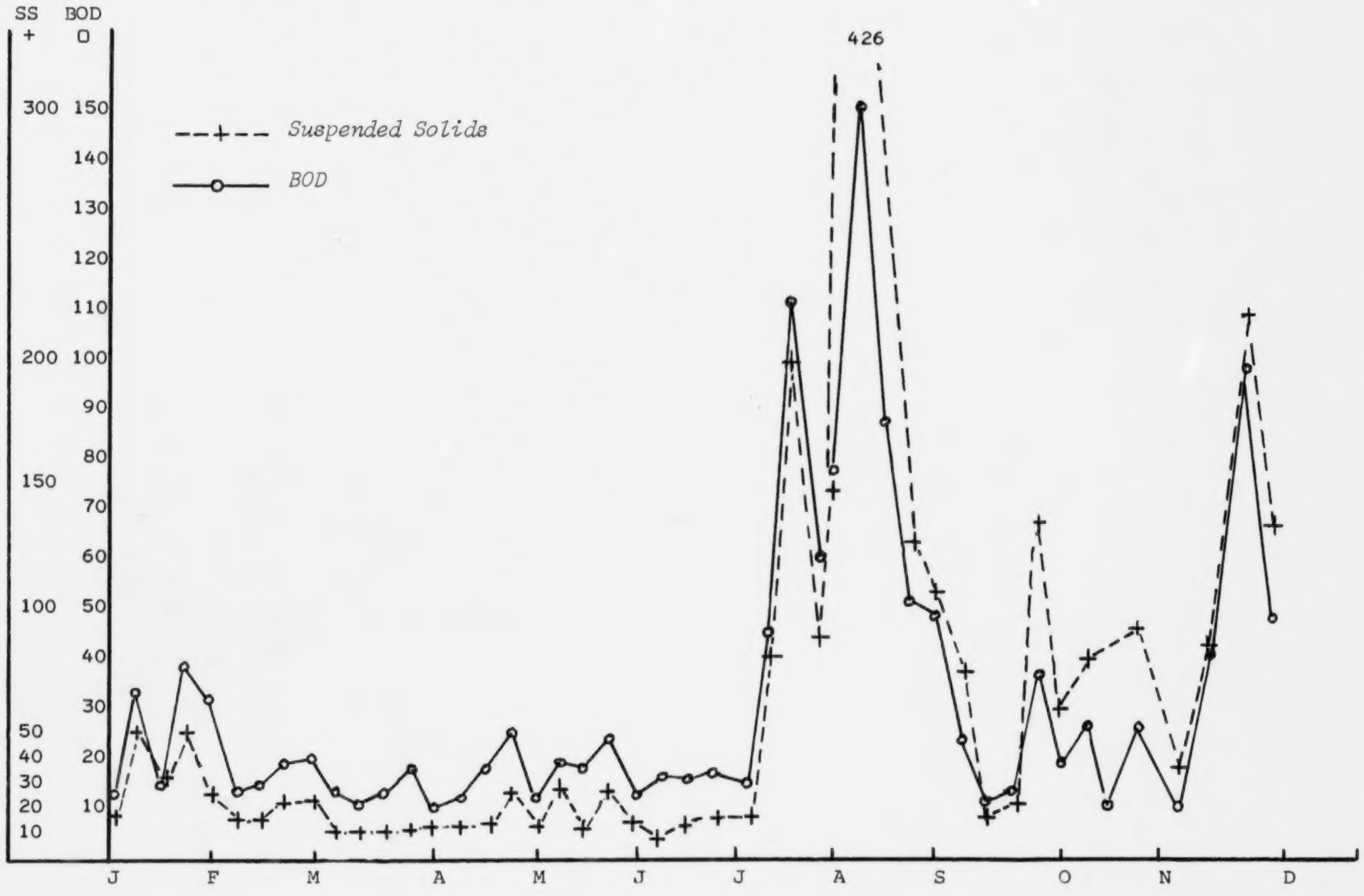


Figure 2. 7-Day Averages of TITP Effluent Suspended Solids and BOD, 1978, in mg/l. Chlorination Mar.-August. Plant Malfunction June-August.

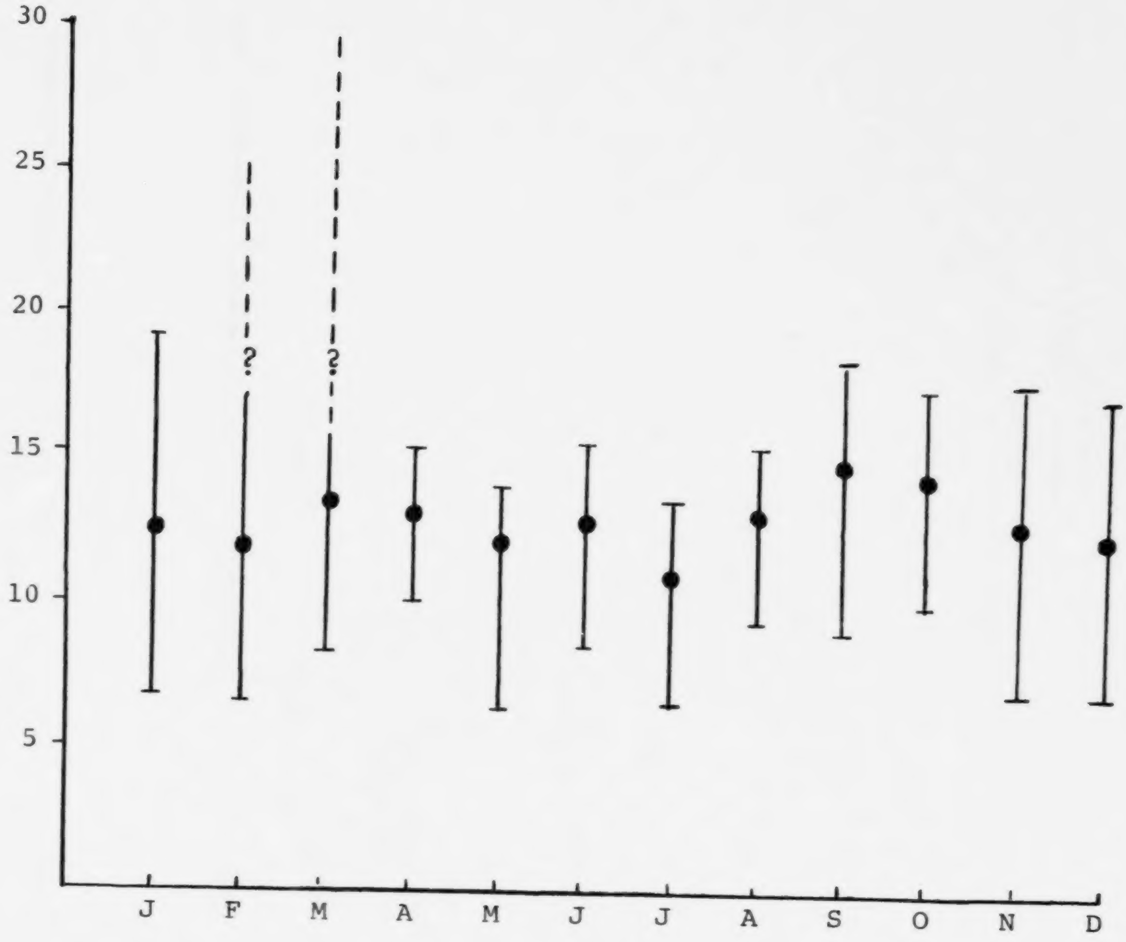


Figure 3. TITP Influent Flow in 1978
(in million gallons per day)

--- dotted line represents failure of flow meter during heavy rainfall

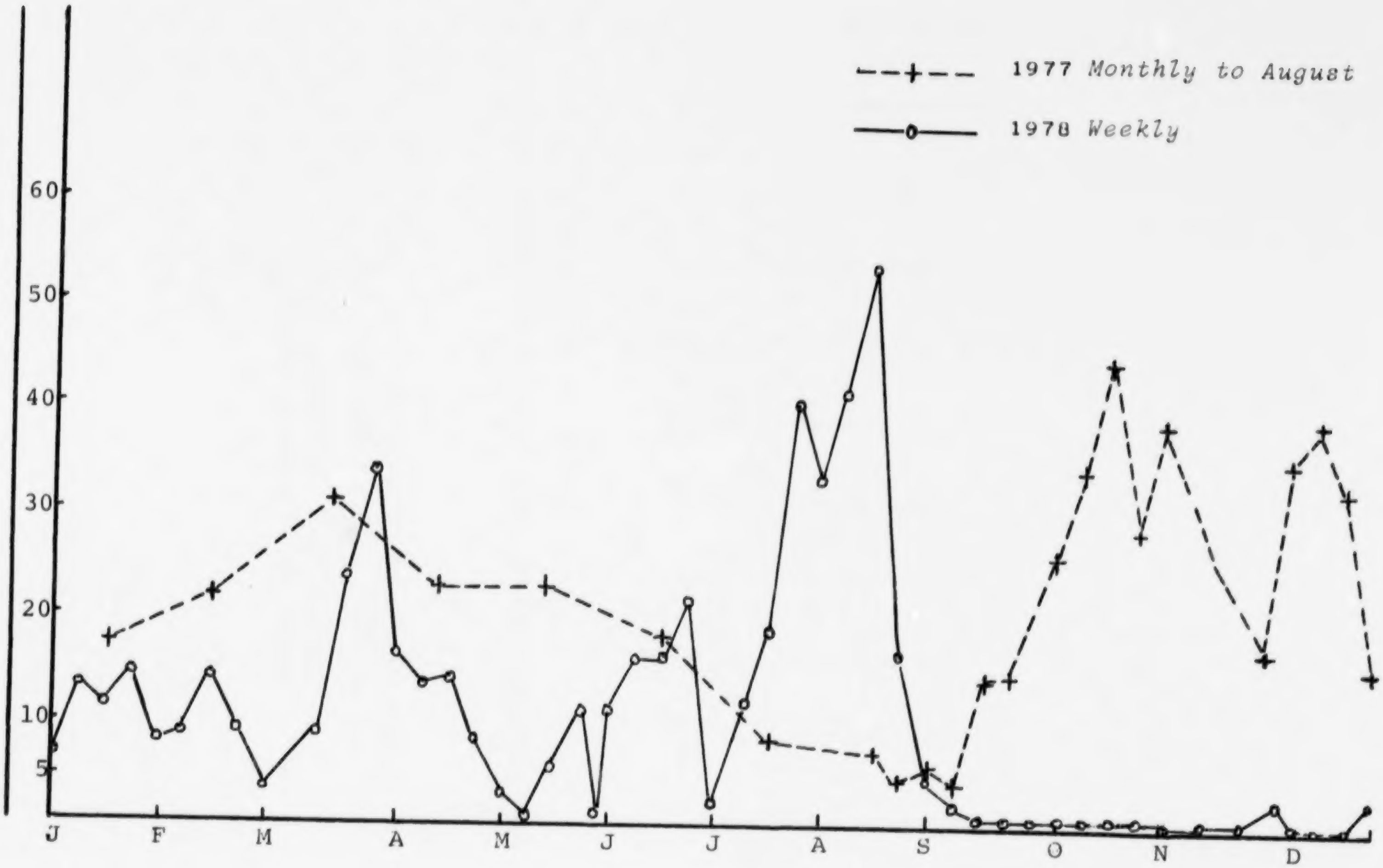


Figure 4. TITP Effluent Ammonia-N, 1977 and 1978, in mg/l.

Notes: Secondary treatment started April 1977; cannery treatment started Oct. 1977
Plant malfunction from June through August 1978.

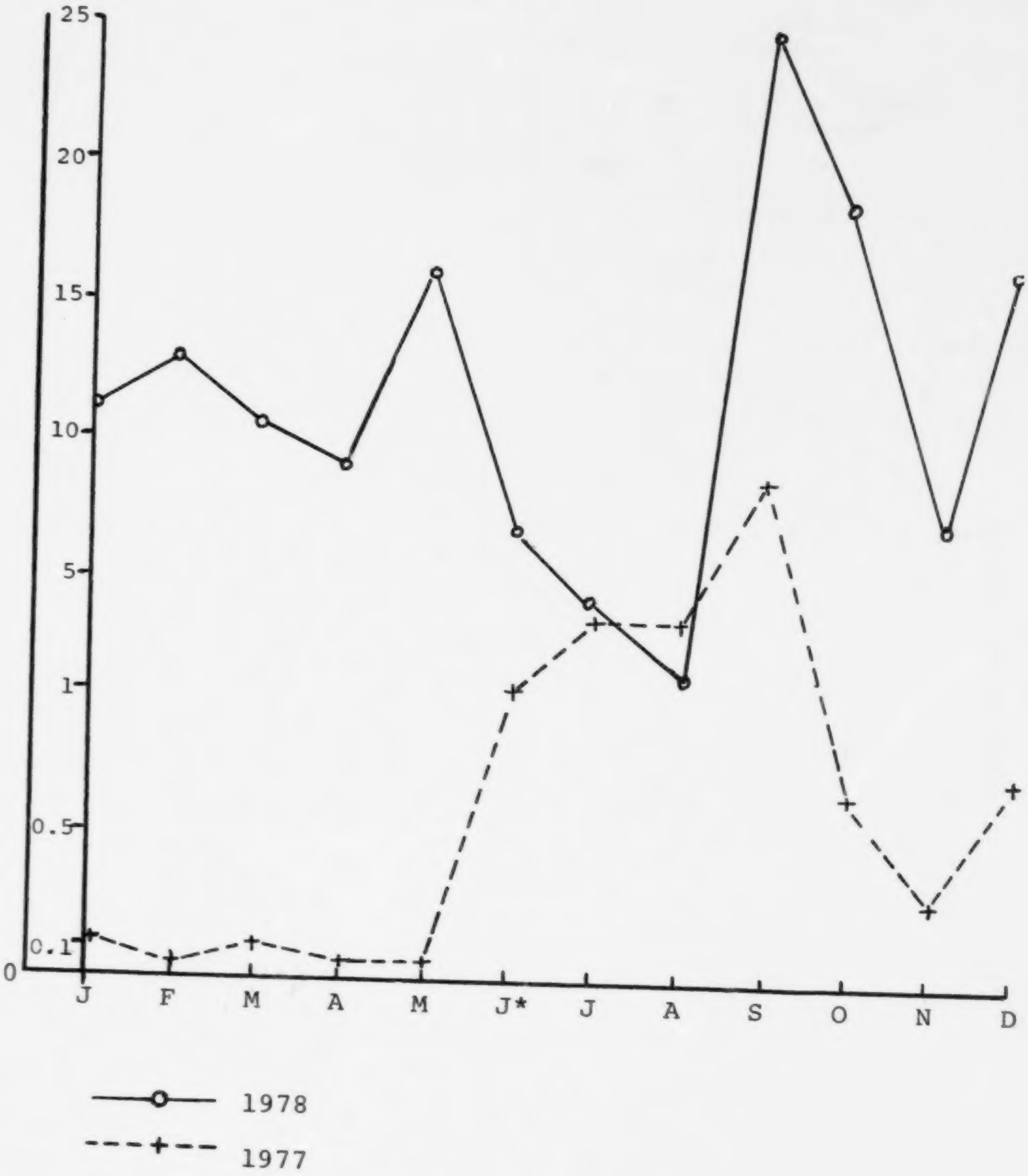


Figure 5. TITP Effluent Nitrate 1977,1978, in mg/l.

*note increase in June 1977 with start of secondary treatment. Nitrite followed same curves.

Breakdown in June & August 1978 show decrease in nitrate.

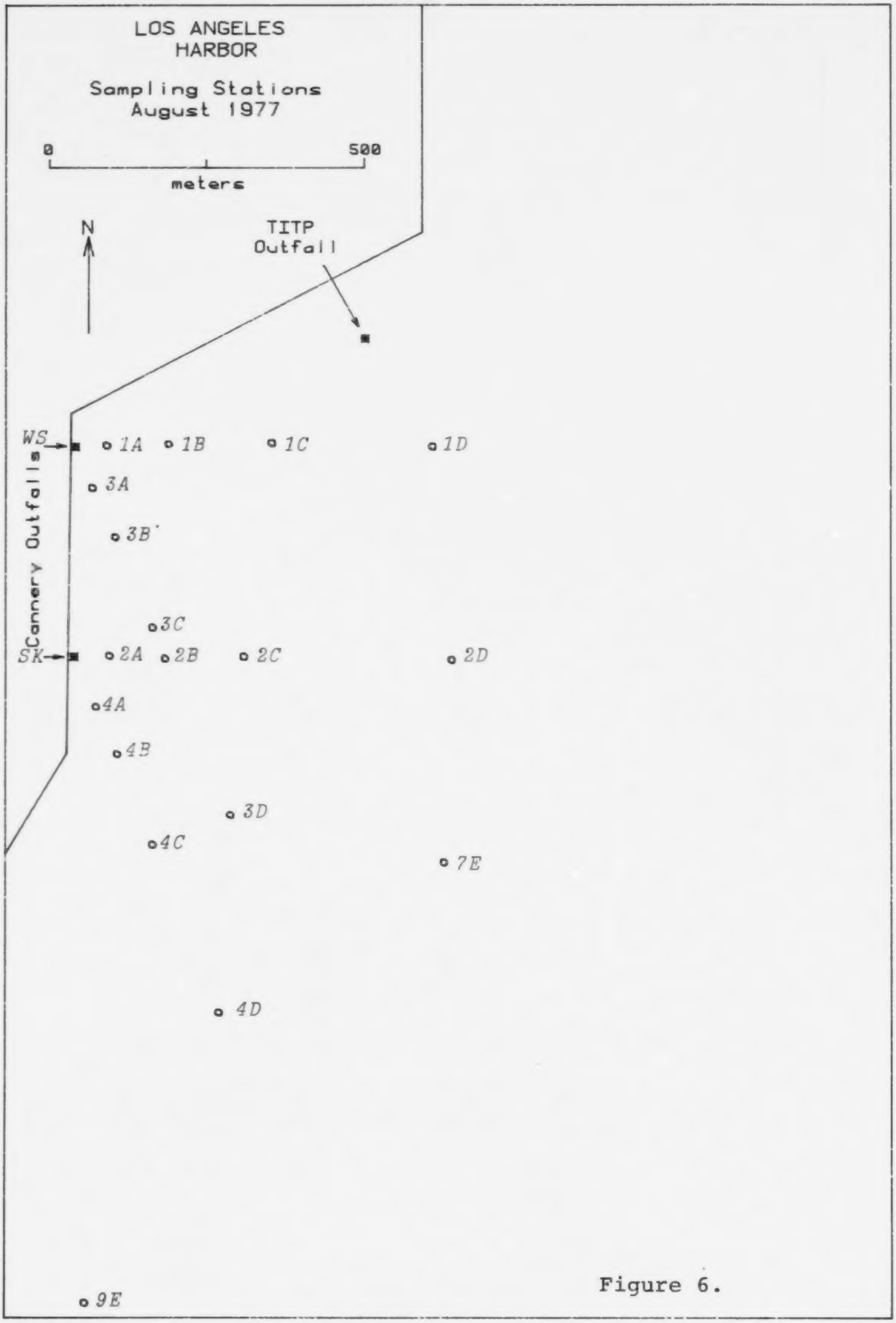

LOS ANGELES
HARBOR
Sampling Stations
August 1977
0
500
meters
N
TITP
Outfall
WS
Cannery Outfalls
SK
1A
1B
1C
1D
3A
3B
3C
2A
2B
2C
2D
4A
4B
3D
4C
7E
4D
9E

Figure 6.

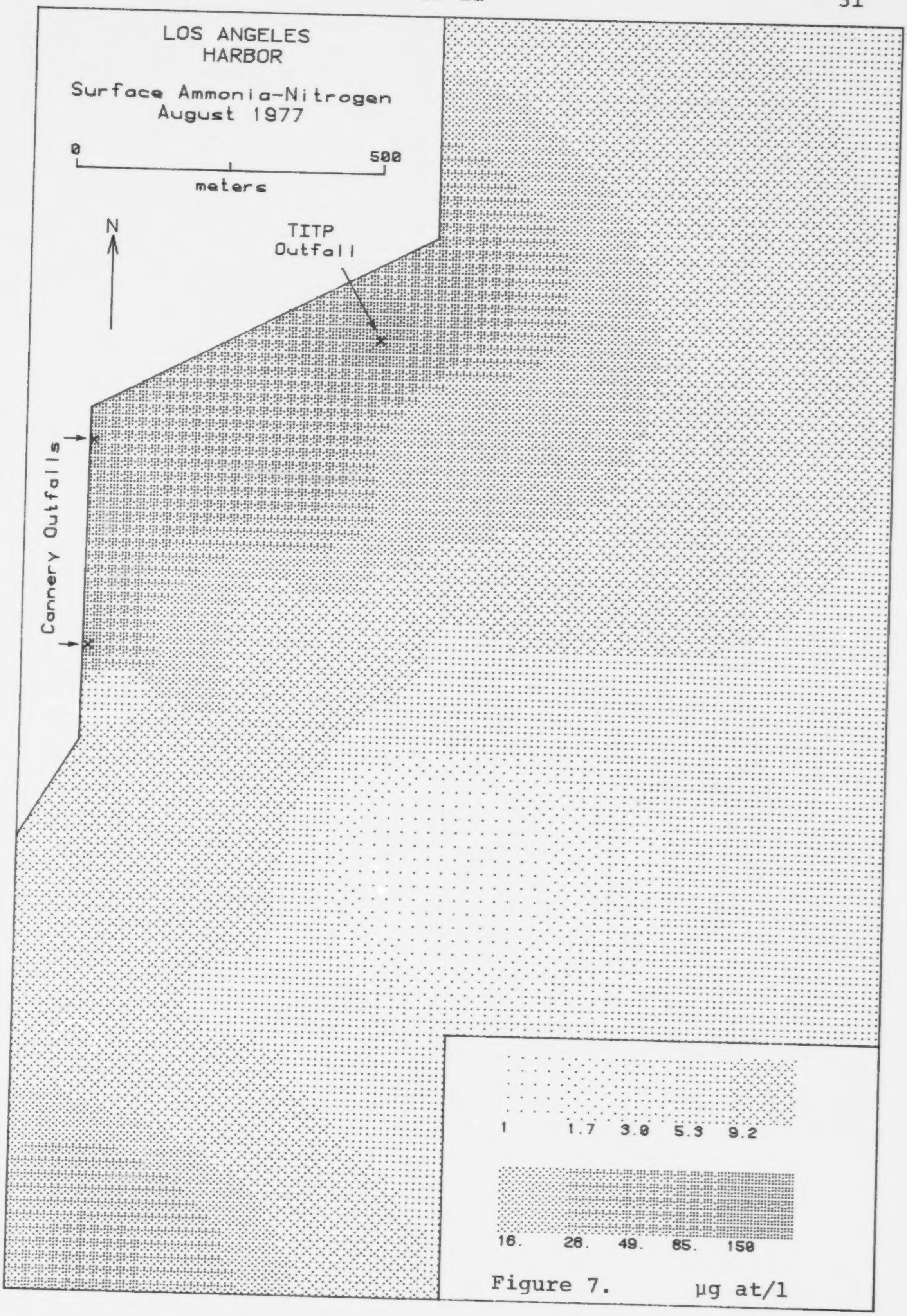


Figure 7. µg at/l

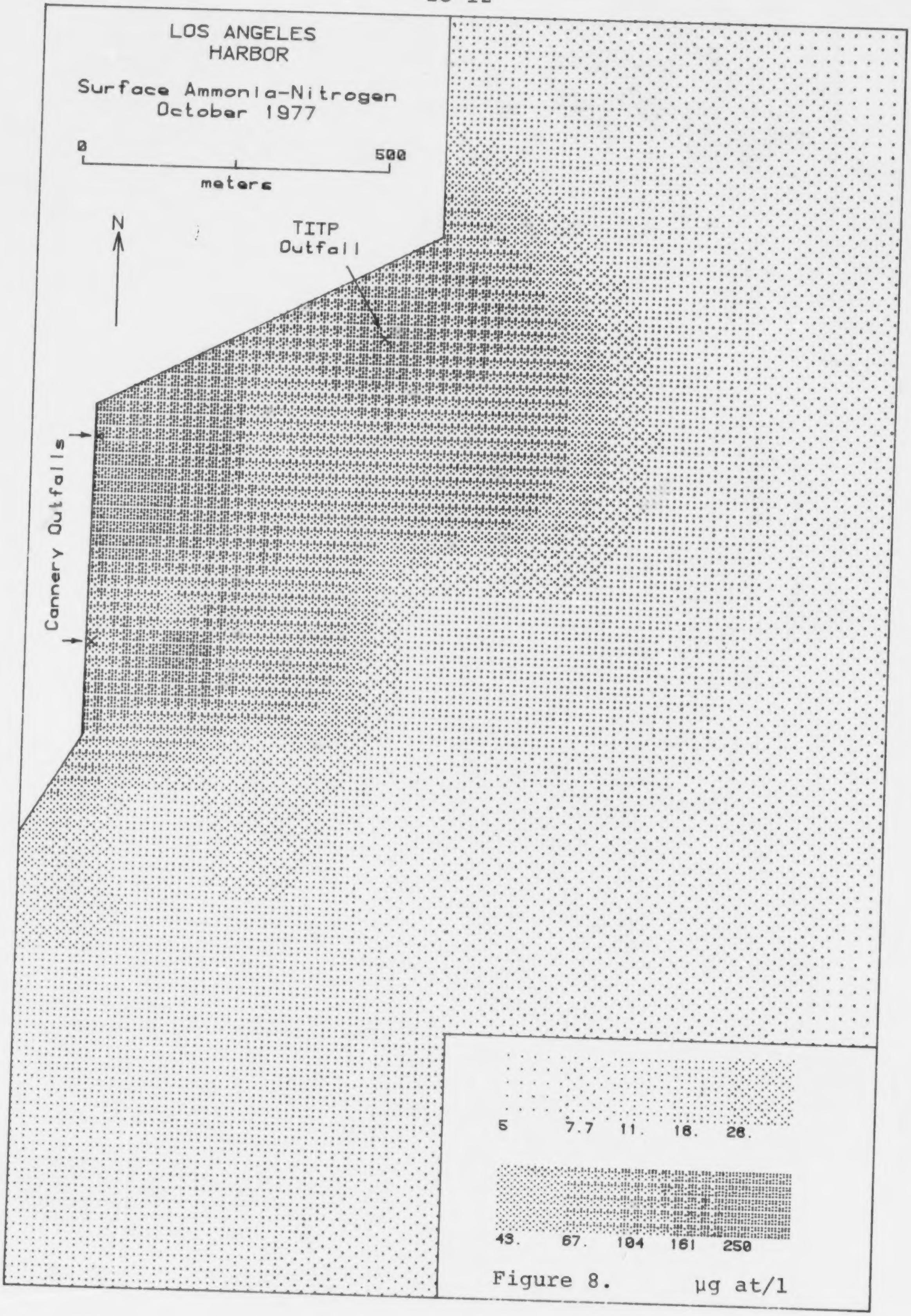


Figure 8. µg at/l

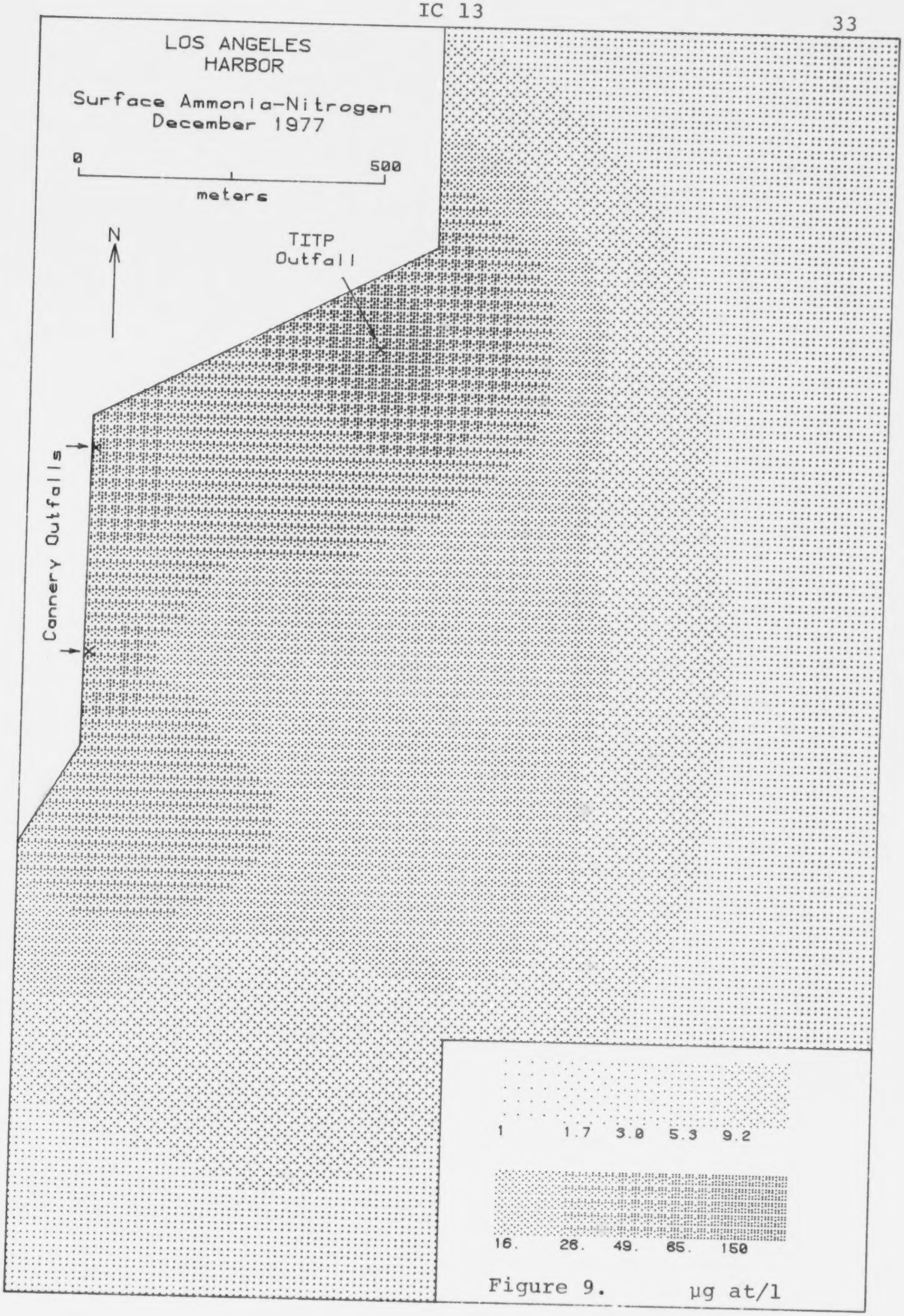


Figure 9. µg at/l

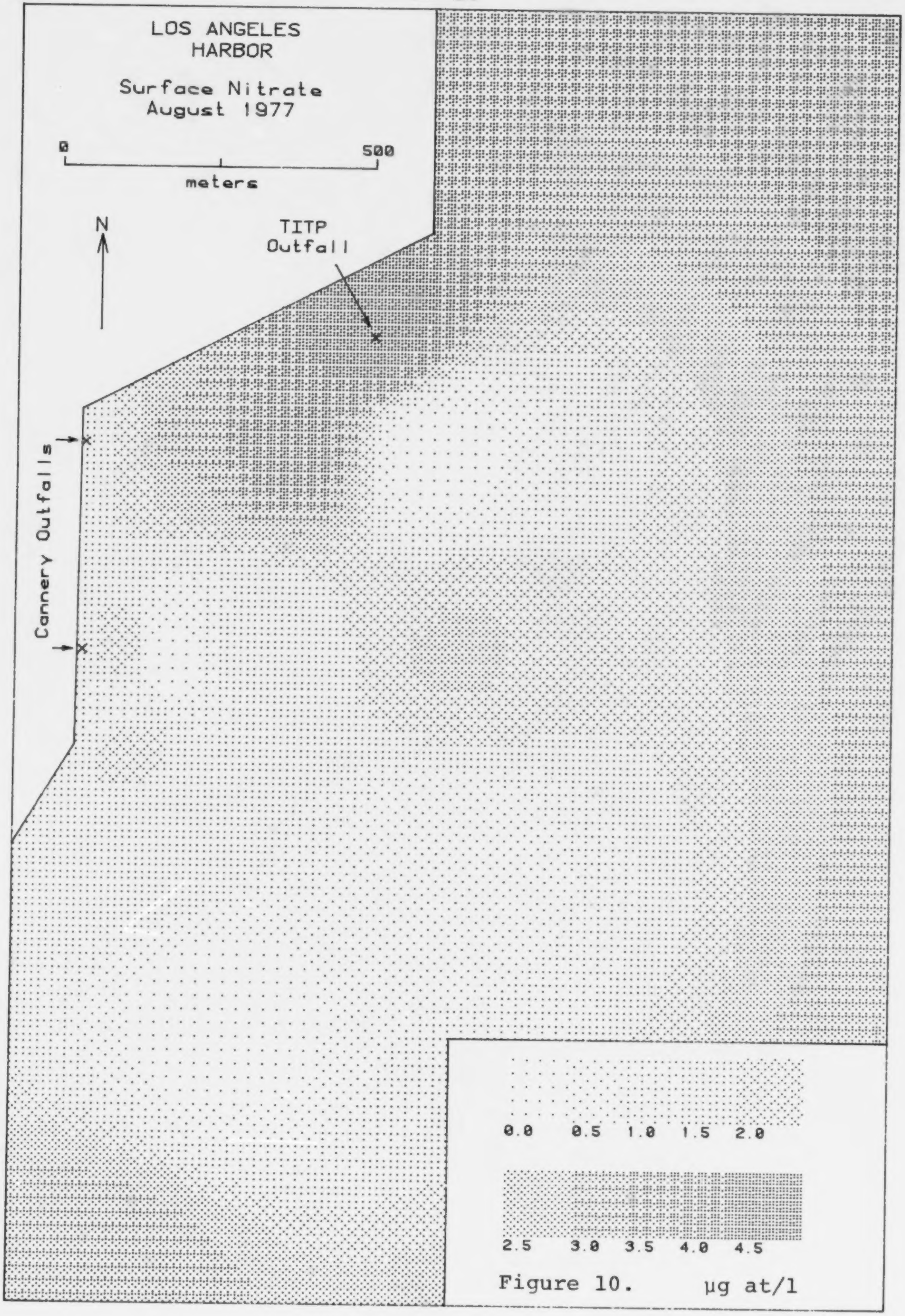


Figure 10.   μg at/l

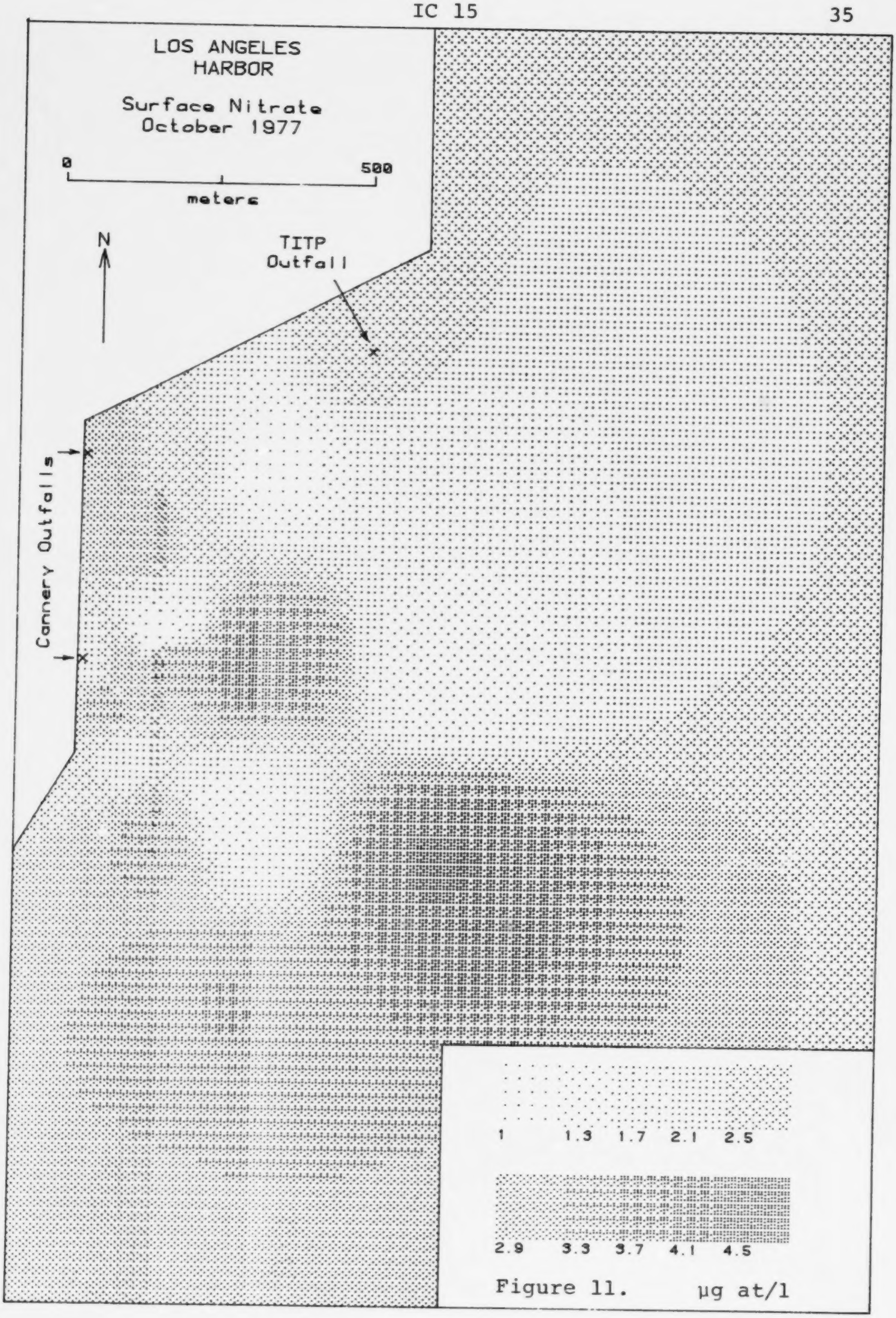


Figure 11. μg at/l

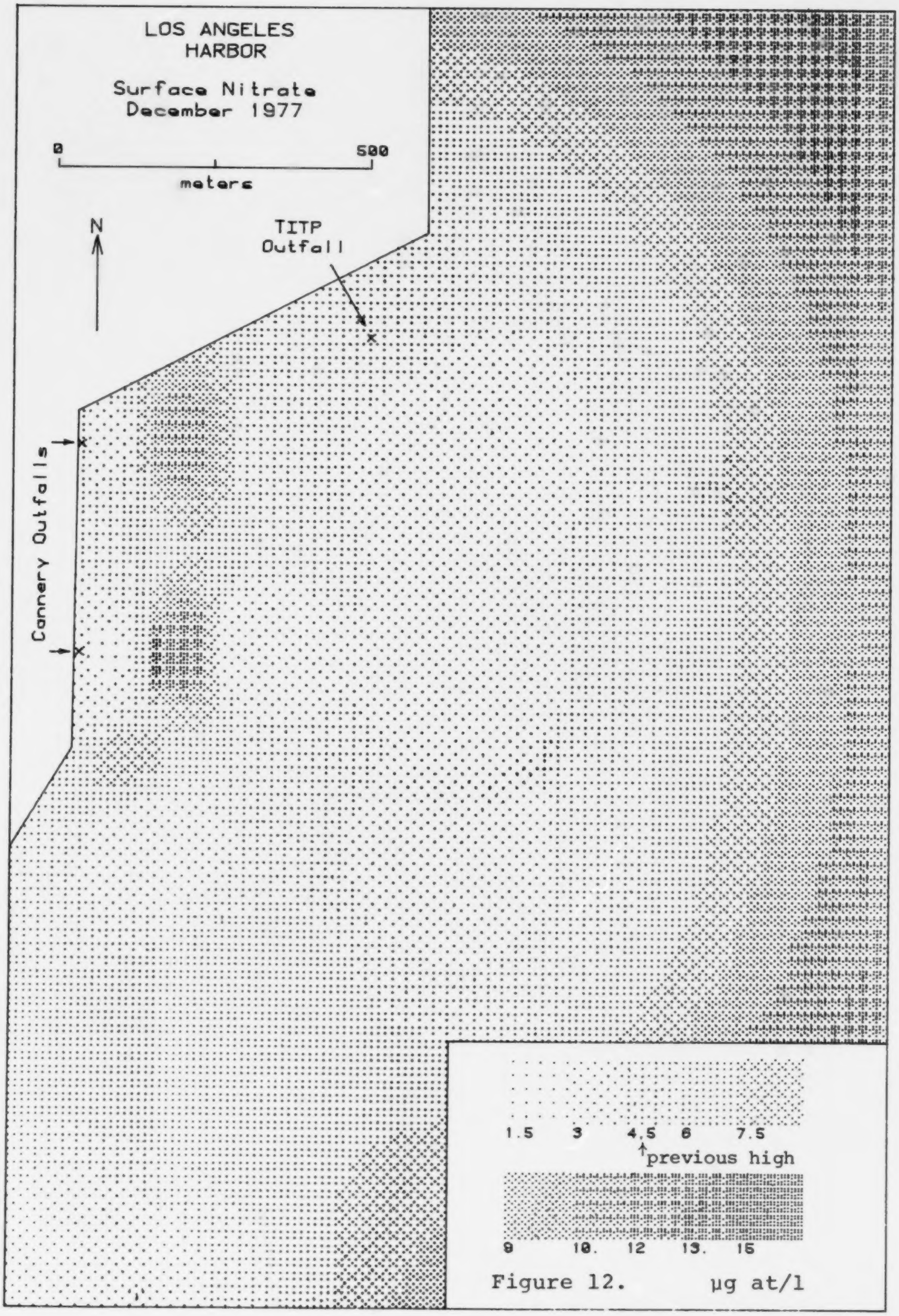


Figure 12. µg at/l

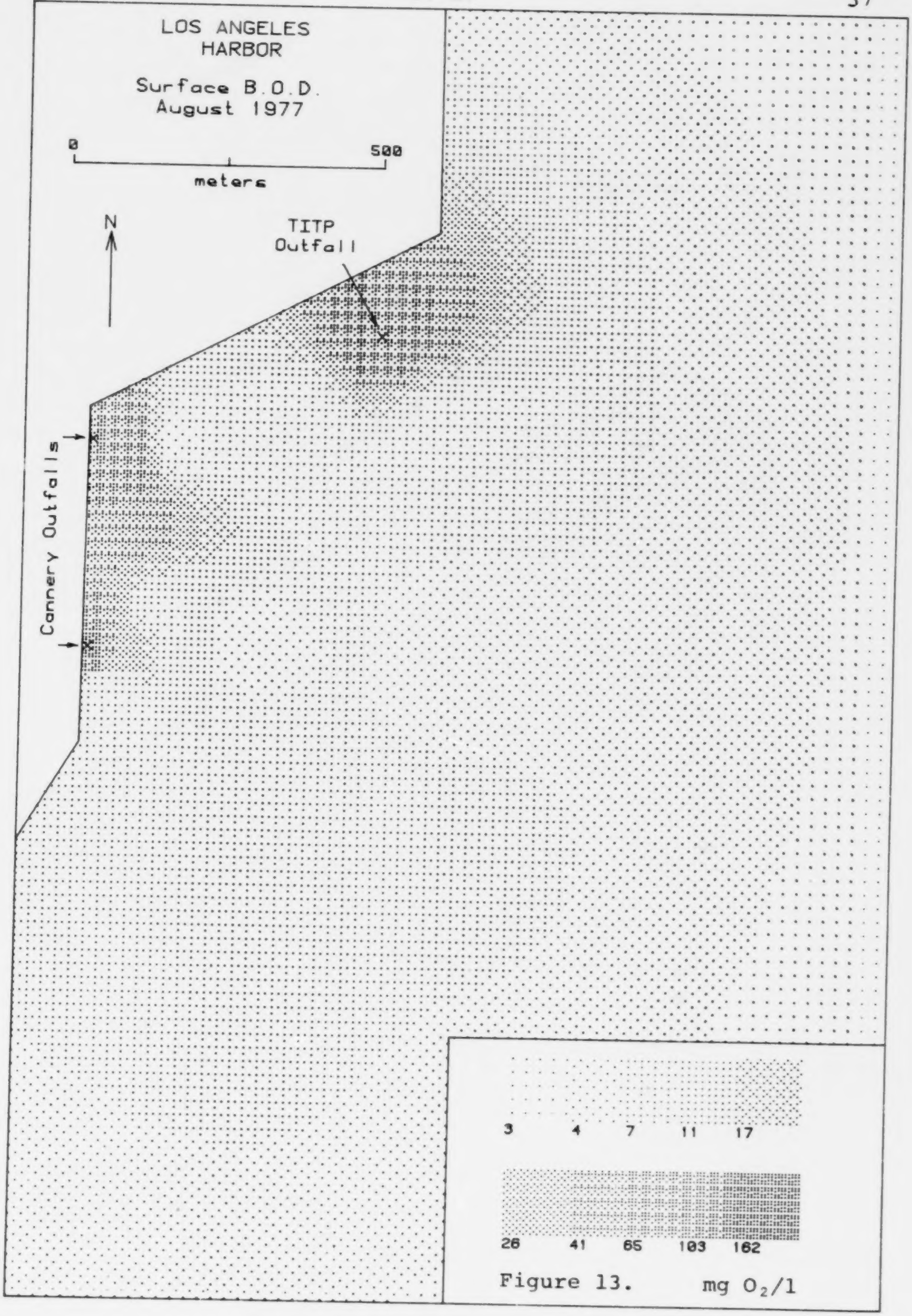


Figure 13. mg O_2/l

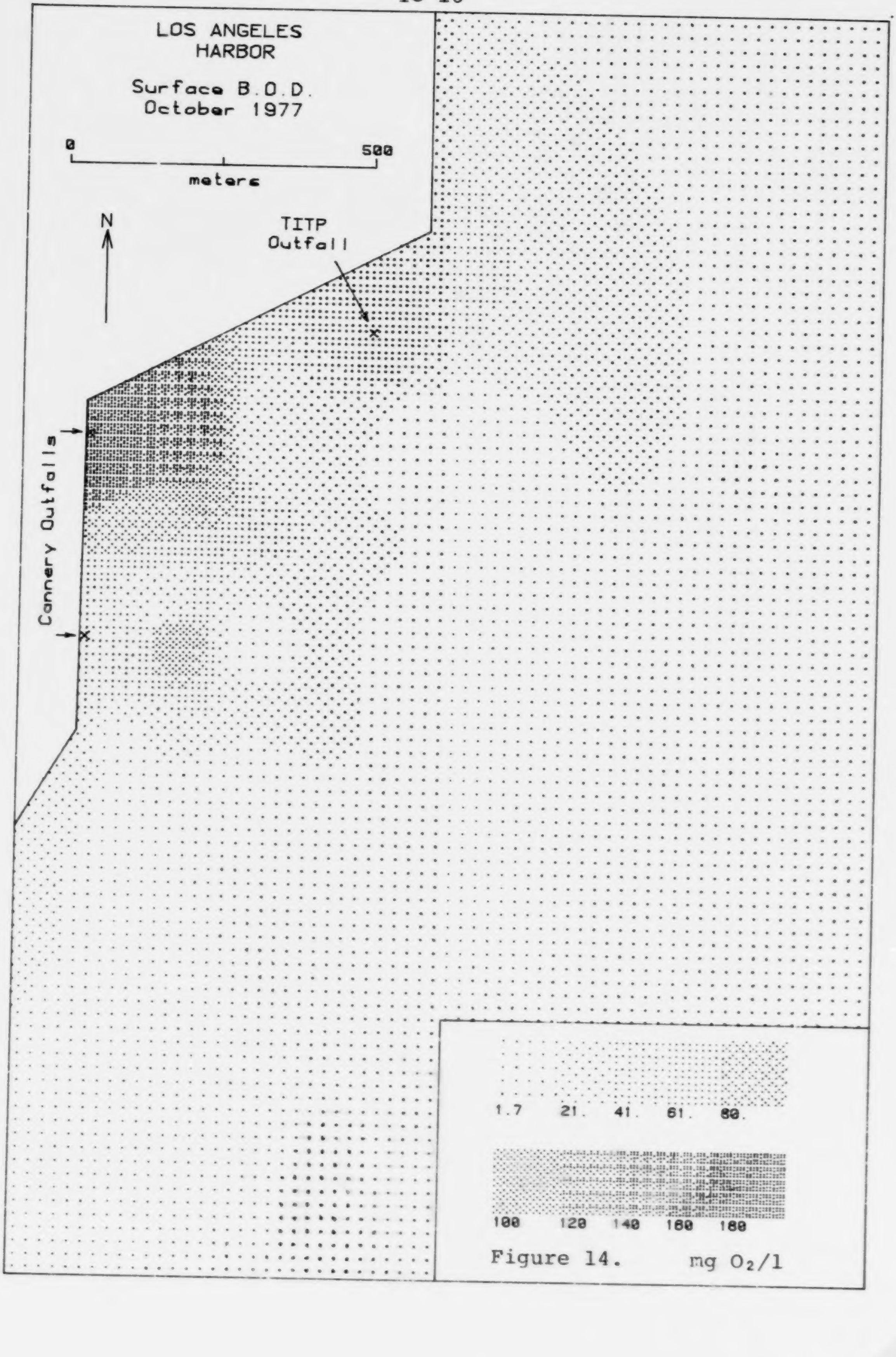


Figure 14. mg O_2/l

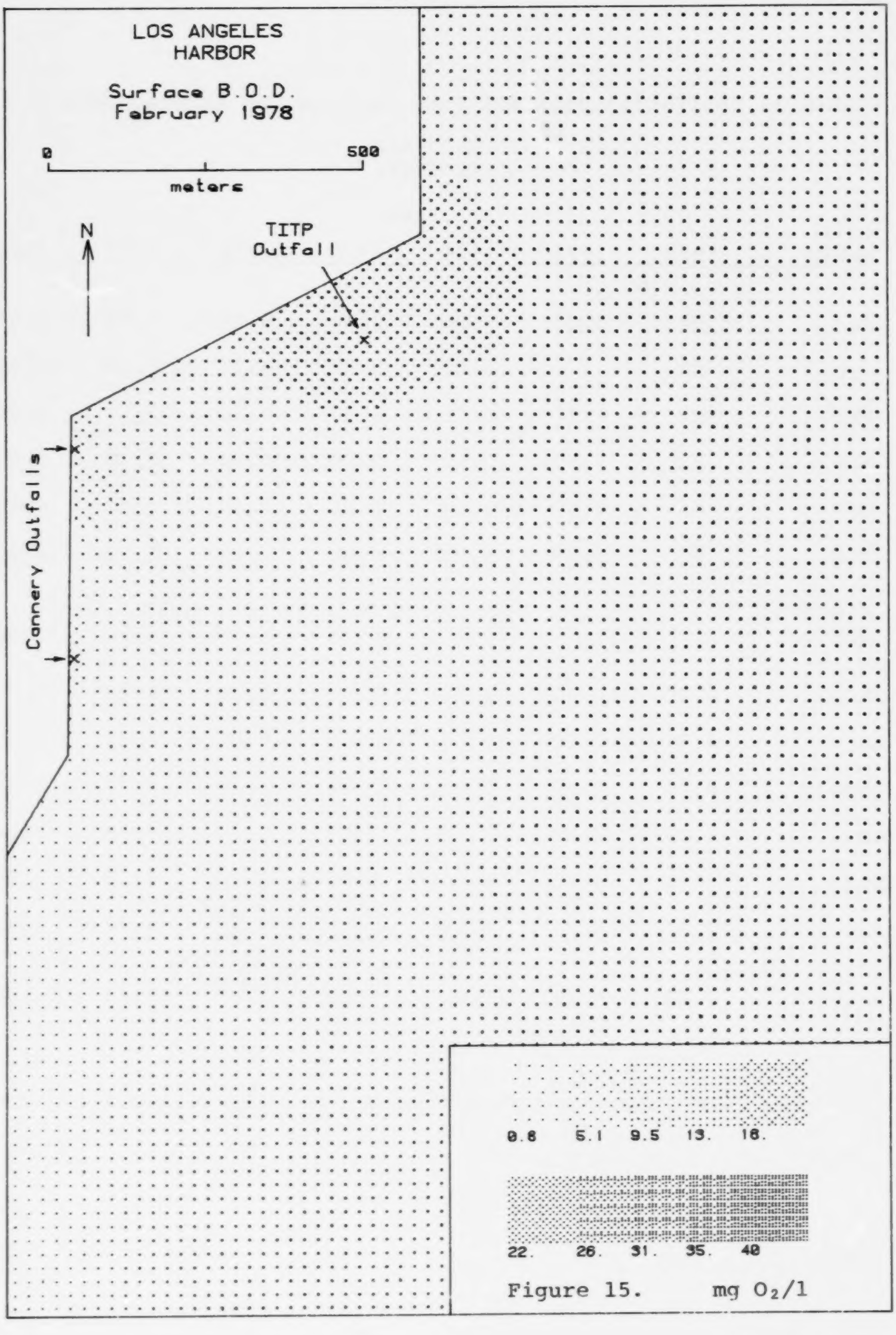


Figure 15. mg O_2/l

Table 1. Unofficial Rainfall Figures from Los Angeles Basin*

RAINFALL
(INCHES)

	YEAR						
Month	1972	1973	1974	1975	1976	1977	1978
Jan	NR	2.67	9.60	0.00	0.00	3.89	7.25
Feb	NR	+	0.00	2.60	4.23	0.15	10.66
Mar	NR	2.70	4.20	3.90	1.70	2.10	8.90
Apr	NR	0.00	0.00	1.60	0.45	0.00	3.00
May	NR	0.00	0.00	0.00	0.10	3.60	0.10
Jun	NR	0.00	0.00	0.00	0.20	0.00	0.00
Winter Cycle		72/73 7.19	73/74 14.55	74/75 12.36	75/76 7.40	76/77 14.84	77/78 37.61
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aug	0.32	0.00	0.00	0.00	0.00	2.20	0.00
Sept	0.00	0.00	0.00	0.00	2.30	0.00	0.58
Oct	0.00	0.00	0.66	0.00	1.10	0.00	0.10
Nov	0.00	+	0.00	0.00	1.10	0.10	1.90
Dec	1.5	0.75	3.60	0.36	0.60	5.40	2.40
Annual (Inc) Total	1.82	6.12	18.06	8.46	11.68	17.44	34.89

*Records from inland Los Angeles Basin by John D. Soule.

CHANGES IN FISH POPULATIONS IN OUTER LOS ANGELES-LONG BEACH HARBORS

INTRODUCTION

Evaluations of the fish populations in the outer harbor area are difficult, due to the many fluctuations in physical, chemical and biological parameters that interact synergistically to influence the populations.

In the present investigations, quarterly trawl studies were carried out in 1977-78 at stations established for the 1973-74 studies (AHF, 1976).

A record was also made by the anchovy live bait boat of catch that is sold only for recreational party boat anglers. The cooperation of Mr. William Verna, bait fisherman, and the California Department of Fish and Game (CDFG) provided relevant data for examination.

Also a monthly survey was made of shore anglers and creel catches in the recreational fishing locations, and weekday observations were made of fishermen and catches around the commercial fish terminal on the Los Angeles main channel.

Offshore catch data from commercial fishing records was examined in an effort to relate harbor populations to adjacent populations in the southern California bight.

A fish egg and larvae census was also carried out at approximately monthly intervals at a series of stations which are various distances from the TITP outfall. The aggregate information makes an interesting picture.

Fish Trawls

The fish trawl report which follows is by Dr. John S. Stephens, Jr., James Irvine Professor of Marine Biology at Occidental College, which operates the research vessel Vantuna:

> ### CHANGES IN FISH POPULATIONS IN LOS ANGELES-LONG BEACH HARBORS AS ESTIMATED FROM TRAWL DATA
>
> "Between May 1972 and October 1973, a detailed study of the fish populations of outer Los Angeles-Long Beach Harbors was conducted by Occidental College (Stephens, Terry, Subber, and Allen, 1974; AHF, 1976) for the Harbors Environmental Projects (HEP). Subsequently, no comprehensive trawling study was conducted in the outer harbor,

though Marine Biological Consultants did some extensive trawling (N = 450) in and around Cerritos Channel (Southern California Edison, June 1977).

"Recently (December 1977), HEP has again sponsored a comprehensive trawling survey in the outer harbor, reoccupying the earlier trawl stations (Figure 1). This report is a summary of Occidental's Vantuna trawling data for Los Angeles-Long Beach Harbors from 1972 to present. The aim of the report is to determine if a systematic change has occurred in harbor fish populations since 1972. A summary of our trawling data is presented by species and year in Table 1. Figure 2 presents a variation in number of fish per trawl from 1973 to the present. Tables 2 and 3 show previously unreported data from July and October 1978.

"As seen in Figure 2, the mean number of fish per trawl showed a rapid decrease (as judged from admittedly limited data) during 1975 and 1976, but appears to have held relatively constant during the last three years, 1976-78. The data from MBC (1974-76) indicated an approximate average of 180 fish per trawl for the three years, which compares favorably with our data during that period (212 per trawl), although their data is summed for the three years and no decrease can be shown. A four-way analysis of variance run on their data, however, indicates significant annual variation though it does not indicate the direction.

"It is obvious from our data that when trawling is not conducted at least quarterly or with comprehensive station coverage, it is probably unreliable (years 1974-October 1977). Our 1977-78 data, however, which consisted of 55 trawls, represents a reliable sample. As mentioned in previous reports, the December 1977 study (Table 1) which averaged only 26.7 fish per trawl was the low point in harbor population levels. In general, December is a month of low fish abundance in the outer harbor. It is interesting that this trawl data corresponds closely to the time of cessation of cannery discharge into the harbor, and it is possible that these two events are related. If so, however, there has been some recovery (or adaptation) of the fish population to changes in nutrient level since December 1977.

"*Curiously, the data from Station 13 presented in Text Table 1 does not correlate closely with that from other stations. During 1972-73, Station 13 was an extremely productive station, averaging 709 fish per trawl (N =8). The dominant fish at this station was *Genyonemus*, the white croaker, and this fact suggested a possible relationship between cannery discharge, croaker abundance, and feeding ecology. Station 13 was the trawl closest to the cannery outfalls and TITP effluent line. Note that the number of species is generally close to the average of 10.0 for the entire harbor in 1972-73.

Text Table 1
Abundance of Fish at Station #13

Sample		No. of fish	No. of species
$\bar{x}$	1971-73	709.2	9.1
December 9,	1977	155	9
December 14,	1977	108	9
April	1978	125	10
July*	1978	993*	10
October	1978	37	7

* editor's note: This coincided with large malfunction of secondary treatment at TITP, resulting in release of suspended solids and high BOD wastes.

"Following cessation of cannery discharge into the harbor and conversion to secondary waste treatment at TITP, abundance of croakers at Station 13 dropped, but was still relatively high as compared to other harbor stations. Then in July 1978, 884 croakers were taken at Station 13, representing about 60% of the croakers taken in that survey. In October 1978, only 24 croakers (7%) were found at this station.

"It is difficult, therefore, to interpret the effect of cessation of cannery discharge on harbor fish populations. Certainly, there is no indication that cessation of discharge has been beneficial to fishes, but because of variations in background levels of populations it is impossible at this time to state that there has been a detrimental effect. Generally, the fish populations in Los Angeles Harbor have shown a rather marked decrease since our 1972-73 study, but similar results from non-harbor trawling data indicate that the decrease may be widespread. Table 4 presents the quarterly data on numbers of fish and numbers of species for all trawls in the 1977-78 survey."

DISCUSSION

The trend in fish populations in the harbor appears to have been generally down since 1971-73, with perhaps a leveling off in 1976-78. One cannot associate this solely with the kinds of waste flow in the outer harbor, but some events coincide in time nevertheless. The Dissolved Air Flotation treatment of fish cannery wastes was installed in 1974-75, reducing the nutrient load to the harbor extensively. The precipitous drop in counts in December 1977 coincided with the diversion of cannery waste into TITP. The start of secondary treatment at TITP in June 1977, when cannery wastes still emptied into the harbor directly, coincided with a more productive fish crop in 1977. The peak in July of 1978 appears to coincide with the breakdown of the treatment plant.

There is no practical method for directly relating the fish populations of the harbor to the wastes. However, the food web does consist primarily of filter feeders that consume bacteria and particulate organic matter, and omnivorous fish species that will feed on filter feeders or directly on particulate organic matter. The food habits of harbor fish were discussed by Reish and Ware (1976) and the habitat preferences tabulated by Stephens *et al.* (1974).

Dr. Stephens was unaware that the large trawl of croakers in July 1978 occurred at the peak period of suspended solids discharge from TITP. In late April, a bloom of filamentous bacteria began that culminated in discharge of floc and floating sludge to the outer harbor (Figure 3) during July and August. This undoubtedly attracted feeding fish and birds and created confusion in interpreting results during expected "secondary" treatment.

A total of 37 species of fish was collected from all trawls in the 1971-73 period, whereas about 20 were collected from all trawls during each 1978 period. In 1972-74 the mean number of species per trawl was 10.0 in Los Angeles Harbor as compared with 10.3 in San Pedro Bay (outside the harbor in the bight). The mean number of species in 1978 was 6, although in the outfalls area the mean was 9.5. Table 4 shows the number of fish per trawl and number of species per trawl for 1978. It appears that TITP is still an important nutrient source.

In species lists and numbers of fish presented for each trawl station for July and October 1978 (Tables 2 and 3), it is important to note the diversity of the catch because the charge has so often been made that the harbor has supported a large population of a few species of "trash" fish.

The white croaker, also called the "sewer trout," is now retailing at close to $3.00 a pound as "butterfish." It is clear, however, that many other fish species are well represented.

Of interest are the generally low numbers of anchovy, *Engraulis mordax*, which was the second most numerous species in the 1972-73 studies. Except for those at Station 13 in

July 1978, when TITP malfunctioned, they were virtually absent from the harbor. Anchovy larvae and juveniles have a much better chance of survival if the first year is spent in a warm environment with plentiful nutrients. They then apparently join the adult stocks offshore when large enough to escape heavy predation. Anchovy were down in the harbor by about 100 fold, whereas they were down about four fold offshore.

Distribution of the major groups of fishes in Los Angeles-Long Beach Harbors in 1972-1973 is shown in Figure 4. The comparison of the mean number of species in the harbor trawls in 1972-73 can be illustrated by comparison of Figure 5, from Stephens *et al.*, 1974 with Figure 6. None of the larger symbols that indicated means above 10 species are seen in 1978, and new, smaller symbols have been added.

Similarly, the mean abundances from 1972-73 are shown in Figure 7 (Stephens *et al.*, 1974), and compared with seasonal means for 1978. The extremely low means for December 1977 in Figure 8, indicate an amazing paucity of fish, with the only population around the sewer outfall area. Figure 9 indicates that the outfall area decreased in April, but the other outer harbor trawl stations had improved; the smallest two means from 1972-73 were the only ones represented, and far lower means occurred in outer Los Angeles Harbor.

The July 1978 trawls reflect the attractant at the sewer outfall when the TITP malfunction occurred. All of the rest of the harbor trawls appeared to have means reduced to the smaller categories of the 1972-73 survey, or below them.

It is recognized that fish catches have been down for several years over most of the eastern Pacific. These have been explained first as due to warmer-than-usual winter water temperatures in 1975-77, or as due to the drought in 1975 and 1976, or more recently, as due to colder-than-normal coastal Pacific waters in 1978. Whatever the reasons, it seems more important than ever to enhance the harbor fish populations by judicious input of nutrients if it is at all possible.

BAIT CATCHES

The data in the previous section showed an almost linear decline over the seven year period in fish caught per trawl. Admittedly the trawl method does not catch several important harbor species, but this is a constant factor in the sampling. It is not possible to compare the trawls with bait catch data directly because the bait boats move according to the occurrence of the anchovy.

The bait fishing boats used nets and also used lighted dories rigged to catch anchovy in the outer harbor. Prior to 1972, estimates were that 50-95% of the small anchovy used by party boat fishermen came from the outer harbor. The harbor yield has continued to decline and the bait boats have ranged farther afield each year to supply the users.

The biology of the northern anchovy and annual anchovy harvest were discussed in the Northern Anchovy Fish Management Plan (Dept. of Commerce, 1978). In 1975, the reduction harvest, the California Department of Fish and Game acoustical surveys and the California Cooperative Ocean Fisheries Investigations (CALCOFI) surveys offshore indicated an enormous anchovy crop on which reduction quotas were based. However, the anchovy apparently failed to recruit in 1976-77, and the survey in 1978 showed a significantly lower stock for the biomass necessary to fish commercially for reduction (to oils and poultry feed).

The histograms in Figure 12 compare bait catches reported voluntarily and are thus subject to inaccuracies. However, it should be noted that the low year of 1976 in the trawl data (Figure 12) contrasts with a large catch, mostly from outside the harbor, according to the bait skipper. The "fishing effort per scoop" has increased greatly as longer distances of travel were required. The summer months are, of course, those with greatest recreational demand, although fishing is a year-round sport in the Los Angeles area. In 1977, the catch in July, August and September exceeded the 1976 catch, corresponding generally to the slight rise in the sparse harbor trawl records.

The 1978 bait catch was extremely low which is in accord with CALCOFI survey data, falling below the catch in most of the years examined. The total catch in 1978 rose somewhat during May, June, July and August, but reached near-normal levels only in September and declined thereafter following the usual fall curve.

Inside the harbor, 1971-74 levels were never again approached, with the 1975-78 means 50 percent or lower than the 1971-74 means. The bait catch was generally high in 1976 and the latter part of 1977. Since fishing effort per scoop cannot be calculated, the comparison is at best, interesting. This evaluation was requested by the California State Water Quality Control Board and the City of Los Angeles.

SHORELINE ANGLERS AND CATCH

Because the harbor has been a popular place for shore anglers, it is important as a recreational resource. More important, however, is the fact that most of these fishermen represent a low socio-economic population nearby and the fish have been a major source of low-cost (no-cost) protein in family diets.

It should be remarked that during the 1973-74 field surveys, numerous anglers were always on hand near the cannery and TITP outfalls. Fists were shaken as the boat drew up to sample because it disturbed the fish. Shoreline interviews elicited the information that some anglers fished with unbaited gang hooks; a good day was a catch in every 2-4 casts, and a bad day was 6-10 casts. This is not reliable statistical information, but it is important to note in light of the 1978 survey, which rated this spot as "poor."

The angler survey, requested by the State WQCB and the City of Los Angeles, was carried out by Donna Cooksey and Michele Smith, who have served as California Department of Fish and Game aides for angler surveys in the past. The fishing areas visited monthly are shown in Figure 13. The results are discussed in the following paragraphs and the data are tabulated in Tables 5-16, appended to this section.

Creel Census

1. Cabrillo Beach Pier - Of the 21 different species sampled, *Genyonemus lineatus* was the dominant fish caught by sportfishermen at Cabrillo Beach Pier, comprising 51% of the of the total fish sampled for the 11 month period. The largest catch of *Genyonemus lineatus* occurred in September, as 203 of the 280 fish caught. Other dominant fish were *Phanerodon furcatus*, *Peprilis simillimus*, *Sarda chiliensis* and *Seriphus politus*. Overall, fishing at Cabrillo Beach was pretty slow, morning or afternoon, averaging only 0.86 fish per rod for the periods sampled. The highest numbers of fish and species diversity occurred during August-October.

2. San Pedro Markets - Of the 8 species identified at the San Pedro Markets for the sampling period, 84% were *Genyonemus lineatus*. The highest catch of fish was seen in March, wnen 160 of the 169 fish sampled were *Genyonemus lineatus*. Access for fishing at the markets was denied in three of the months sampled and was dependent on the market activities. Overall, fishing at this spot was usually very productive.

3. Ports of Call - *Embiotoca jacksoni* dominated the catch at Ports of Call, comprising 83% of the total fish caught during the sampling period. Species diversity was very low, only 3 species total, as also was the fishing effort. In 6 of the 11 months sampled, there were no fishermen present at this area.

4. Outfall Area - The dominant fish sampled at the outfall area was *Genyonemus lineatus*, accounting for 69% of all fish sampled for the 11 month period. Also well represented in the catches were the surfperches, Embiotocidae, and the silversides, Atherinidae. Diversity for the entire period revealed only 14 species. Overall, fish catch numbers and fishing effort was lower at this area than our other harbor areas. In general, fishing at this spot was "poor."

5. Fish Harbor - Of the 22 species identified at this location, *Genyonemus lineatus* accounted for 59% of the catch. The surfperches were well represented by *Embiotoca jacksoni*. Fishing in this area was relatively consistent, although not very productive.

6. Navy Mole - *Embiotoca jacksoni* dominated 40% of the catch on the Navy Mole for the sampling period. *Genyonemus lineatus* was observed as 20% of the total catch. Species diversity was high, showing 28 species total for the 11 month period. Members of the Serranidae were also caught frequently and almost always were short (less than 12"). For this reason, several people would not allow us to see their fish.

7. Queen Mary - The most diverse area was near the Queen Mary, where 36 species of fish were found. The dominant species was *Genyonemus lineatus*, comprising 72% of the total fish sampled. Other species well represented were *Embiotoca jacksoni*, *Synodus lucioceps*, and *Cymatogaster aggregata*. Fishing at this spot was usually pretty consistent.

8. Los Angeles River - The dominant fish at the Los Angeles River area was *Genyonemus lineatus*, accounting for 82% of the total fish. The highest catch of *Genyonemus lineatus* occurred in July, when it composed 96% of the total fish. Of the 18 species found at the river spot, *Cyprinus carpio* was seen only once, in July.

9. Alamitos Blvd. - A total of 26 species was found at the Alamitos Blvd. area. *Genyonemus lineatus* accounted for 49% of the fish sampled. The surfperches were represented by *Embiotoca jacksoni*, *Phanerodon furcatus* and *Cymatogaster aggregata*. The largest catches of fish occurred during the fall months, August-October.

10. Belmont Beach Pier - *Seriphus politus* dominated as the most numerous fish caught during the sampling period (57%); however, *Genyonemus lineatus* was also prominent. On a seasonal basis, *Seriphus politus* dominated the summer months, and *Genyonemus lineatus* dominated most of the rest of the year. The surfperches were well represented, but not in the large numbers seen for the Sciaenidae.

SUMMARY OF CREEL CENSUS

The species diversity was comparatively high, 34 species, and included one freshwater species, *Lepomis microlophus*. Generally, the highest species diversity was found at the larger sampling locations, such as the Navy Mole, Queen Mary, and Belmont Pier. *Genyonemus lineatus* was overall the most predominant species, followed by members of the family Embiotocidae, *Embiotoca jacksoni*, *Phanerodon furcatus*, and *Cymatogaster aggregata*. This differs from Pinkas, Oliphant, and Haugen's 1968 report in which *Seriphus politus* was the dominant species caught in southern California, followed by *Genyonemus lineatus* and *Sarda chiliensis*.

Inherent in the sampling were certain sources of error relating to time. One sampling bias was that sampling was done only on the weekends when many recreational fishermen were out; sampling was on Sundays for the first part of the year and then on Saturdays toward the end of the year. The route was varied, starting at 8:00 AM at Belmont Pier for three out of eleven samples, and starting at Cabrillo Beach at 8:00 AM for the other eight samples. Little significant difference was found in the data between the two route times. Adverse weather influenced sampling only once (July) with a corresponding decrease in the number of fishermen.

COMMERCIAL PARTY BOAT ANGLER RECORDS

The California Department of Fish and Game has kept records of anglers' destinations and fish caught off of southern California for a number of years (Wine and Hoban, Dec. 1976; Maxwell and Schultze, 1976 a, b, c; 1977 a, b, c; Black and Schultze, 1977; Crooke and Schultze, 1977; Crooke, 1978; Wine, 1978; and CDFG, unpublished data, 1978). The shelf waters are divided into blocks (Figure 14) and the data recorded for each block. In southern California, party boats are large and may carry 50 or more anglers for day trips or longer. This contrasts with other areas of the country where sportfishing usually consists of smaller boats carrying only a few people seeking larger game fish.

In order to determine whether any long term annual trends in total fish populations could be seen in coastal waters for comparison with harbor water trends, data from nearby fishing blocks 718, 719, 720 and 740 were examined for the years 1970-1977. The complete 1978 data are not yet available, however.

A strong downward trend was seen in harbor fish trawl data from 1974-1978 (Figure 2), but the bait catch data did not show a similar pattern. Thus, this effort was made to see whether a trend could be found in nearby coastal waters similar to the harbor.

Block 719 includes the rocky coastline off Point Fermin and White's Point, waters outside the breakwaters from San Pedro to Long Beach and some sandy bottom areas. Block 718 lies east of this, roughly from Long Beach to Huntington Beach; bottoms there tend to be sandy or muddy. Block 720 covers the rocky coast, including Point Vicente and Rocky Point, including some kelp beds. Block 740 lies offshore, adjacent to 719, roughly intermediate between Long Beach and Santa Catalina Island. Deeper bottoms may be sandy or muddy, with isolated reefs.

RESULTS OF PARTY BOAT CATCH

Long Term Trends. Plots of total number of fish per year (Figure 15) showed varied patterns for blocks 719, 720 and 740, with a net upward trend increase in numbers from 1970 to 1977 only in block 719. The reverse, however, was shown for 718, which had a steady decline in numbers for the same years. In total numbers, block 719 was lowest in 1970 and 1971, second lowest through 1976, and highest in 1977. However, when number of fish per hour, number of fish per angler, and number of fish per boat day were considered, 719 was generally highest or second highest, being third only in 1970 and 1971. Table 17 gives the mean abundances for 1970-1977.

In terms of total fish caught between 1970 and 1977, block 719 ranged from second lowest to second highest, with the mean intermediate between 718 and 720 and slightly less than that for 740. When number of fish per angling hour was plotted, the range for 719 overlapped that of the three other blocks and the mean was highest of the four blocks. The mean number of fish per angler was higher for block 719 than for 718 or 720 and slightly lower than for 740. Number of fish per boat day showed the range for block 719 to be considerably greater than for either 718 or 720; this range was overlapped at both ends of the scale by the range for block 740, but the mean number of fish per boat day for block 719 was considerably higher than that for the other three adjacent blocks.

Over all years, the species caught in the greatest numbers in block 719 were, in descending order: rockfish (23-87% of total annual catch); sculpin (6-12%); Pacific bonito (0.1-34%); and ocean whitefish (0.8-9%) Analyses of catch data for the species in all four blocks showed the following:

Catch by Species

Rockfish:

Catches in block 719 were generally intermediate - lower than in 740 and 720; higher than in 718 (total annual catches, however, were generally higher in 740 and 720, lower in 718). Catches of this species followed roughly the same pattern in all four blocks, with peaks in 1974-1978. The only exception to the pattern lay in the fact that, in 1977, catches dropped in all blocks but 719, where there was an increase of 60,000+ over 1976. Total annual catch, however, nearly doubled in these years in 719, but either dropped or remained about the same in the other three blocks.

Sculpin:

Catches were generally higher in block 719 than in the other three blocks. The patterns were similar in 719 and 740 and less so in comparison with 719, 718, and 720. Peaks occurred in 1971 and 1973 and a threefold increase was found from 1976 to 1977 in 719, paralled, but to a much lesser extent in 740. In contrast, catch dropped sharply in 720 and remained about the same in 718. Total annual catch in these two years doubled in 719, dropped in 718 and 740, and increased slightly in 720.

Pacific Mackerel:

Catch in all four blocks showed an alternating pattern of high and low years, despite differences in total catch for all species. Peaks occurred in 1971, 1973, and 1975. Very sharp increases in 1977 were most pronounced in 719, intermediate, but still substantial in 720 and 740, and much less dramatic in 718.

Pacific Bonito:

Pattern of catches were similar in 719 and 740, with peaks in 1970, 1972 and 1976. Blocks 718 and 720 were also similar, although peaks and drops in 720 were by far the most abrupt. Lows for all four blocks occurred in 1971 and 1974. Catches in block 720 generally were 2-3 times that of the other blocks, although the same proportion was not necessarily reflected in total annual catch. Block 719 was intermediate, generally higher than 740, but lower than 718 and 720.

Ocean Whitefish:

Roughly similar patterns occurred in 719 and 720, with a sharp increase in 1977. Except for the last year, the same trends appeared in 740 and, on a much more moderate scale, at 718. Peaks occurred in 1970 and 1973 in all blocks; there was a substantial drop from 1976-77 in 740.

Rock Bass:

Rock bass was the sixth most commonly caught in 719, ranked first in 718, third in 720, and fifth in 740. The total caught from 1970-77 in 719 was 39,934, compared to 238,679 in 718, 121,278 in 720, and 60,240 in 740. In all four blocks, the number caught dropped sharply from 1973 to 1974, with few or none reported through 1977. Except in 720, catch peaked in 1971 and dropped off through 1972-73, ending in the steep drop in 1974.

Barred Sand Bass:

Barred sand bass was the third most commonly caught species in 718; seventh in 719, ninth in 720, and eighth in 740. It comprised 13% of total catch in 718 in 1970, dropped to 3% or less in 1971-73, jumped to 25% in 1974, remained high through 1976, dropped again in 1977. In 719, catch was low through 1975, up to 7% of total in 1976, and dropped in 1977. In 720, catch remained low (0.1-2% of total) throughout. In 740, catch was low through 1974, up in 1975 and 1976, down again in 1977.

California Barracuda:

California barracuda was the fifth most commonly caught in 718; highest in 1970, it was much less commonly caught from 1971-1975. It increased in 1976-77, though only to 2-5% of total as compared to 17% in 1970. A similar pattern occurred in 719 and 720. Numbers were relatively constant from 1970 to 1973 in 740, with a drop in 1974-75 and, as in other blocks, an increase in 1976-77.

Halfmoon:

Halfmoon was the fourth most commonly caught species in 720. It was very low in 1970, rising abruptly in 1971 and remaining fairly stable thereafter except for a drop in 1976. The patterns in the other three blocks were somewhat similar except that low years included 1974 through 1976. Numbers caught were consistently much lower than in 720.

Annual Catches of Dominant Species by Block

Block 718

Over all years (1970-77) - highest catches:

1. rock bass
2. rockfish
3. barred sand bass
4. Pacific bonito
5. California barracuda

Rock Bass:

Steady decreases occurred in number caught from 90,131 in 1970, to none in 1977. It comprised 52% of total catch (86,509) in 1971, 35-39% in 1970 and 1972-73, dropping to 7% in 1974, although total annual catch increased by 8,000. The total annual catch also declined from 1970-77, but not as sharply as the number of rock bass caught in this period declined.

Rockfish:

The catch was variable, ranging from 3,058 in 1977 to 36,678 in 1974. Percent of total catch ranged from 5% in 1970 (11,368 caught) to 50% (36,678) in 1974. In terms of number of fish caught, the highest years (25,000+) were 1971, 1972 and 1974. Ten thousand-18,000 were caught in 1970, 1973 and 1975, and less than 10,000 were caught in 1976-77.

Barred Sand Bass:

The catch was very low, ranging from 0.4-3% of the total (268 to 4,750) in 1971-73; it was relatively low in 1977 (6,656), but was equal to 23% of total for the year. Otherwise, it ranged from 13-62% of the total. In 1970, 31,672 (13%) were caught, dropping to 4,750 (3%) in 1971. The catch continued to drop in 1972-73 (378 and 268, respectively), increased sharply to 17,856 in 1974, continued to increase through 1975 to 34,290, and dropped again in 1977.

Pacific Bonito:

The number caught decreased fairly steadily from 1970 to 1977. It dropped from 40,533 (17% of total) to 15,816 (18% of total) from 1970-1972, increased to 17,939 (28% of total) in 1973, dropped to 333 (0.5%) in 1974, and remained low through 1977.

California Barracuda:

California barracuda comprised 17% (40,852) of the total catch in 1970. In all other years catch was low, ranging from 59 caught (0.09%) in 1975 to 1,425 (5%) in 1977.

Block 719

Over all years (1970-77), highest catches:

1. rockfish	23-87% of total for year
2. sculpin	6-12%
3. Pacific mackerel	0.6-18%
4. Pacific bonito	0.1-34%
5. ocean whitefish	0.8-9%

Rockfish:

There was a steady increase in numbers caught from 1970-74, from 12,709 to 148,396 (23 to 87% of total for year); roughly the same level was maintained from 1975-77, of approximately 100,000-170,000 (60-85% of totals for year).

Sculpin:

No apparent pattern was seen for sculpin over 1970-77; the number caught ranged from 5,671 in 1972 to 25,899 in 1977, but percent of total catch did not vary considerably (4% in 1972 to 12% in 1970).

Pacific Mackerel:

The catch was variable, high one year and low the next; the number caught ranged from 710 in 1970 (1% of total for the year), to 54,055 in 1977 (18% of total for the year). Low years included 1970; 1972 (3,186 or 2% of total); 1974 (953 or 0.6%); 1975 (3,254 or 2%); and 1976 (4,764 or 3%). Higher years were: 1971 (9,611 or 10%); 1973 (9,210 or 5%); and 1977 (54,055 or 18%).

Pacific Bonito:

High catches occurred in 1970-1973; there was a drop in number caught from 1974-77. The percents of total catch for 1970-73 were from 10 to 34%; for 1974-77, they were from 0.1 to 2%. The number caught from 1970-73 ranged from 16,455 to 23,798; in 1974-77, the range was 178 to 3,004.

Ocean Whitefish:

Numbers caught increased from 1975-77 (3,409 to 25,446); during prior years the catch was variable, ranging from 888 to 5,087. The percent of total catch generally was about 2-5%, varying from 0.8% in 1974 (1,427 caught) to 9% in 1977 (25,446 caught).

Block 720

Over all years (1970-77) highest catches:

1. rockfish
2. Pacific bonito
3. rock bass
4. halfmoon
5. Pacific mackerel

Rockfish:

Rockfish was the dominant catch for all years, comprising 38% (1970) to 84% (1975) of the total for the year. The number caught ranged from 67,070 (1977) to 302,354 (1975). The percent of total catch was lowest in 1970 and 1977; it remained at 52-58% from 1971-73, increased to 83-84% in 1974-75. The catch dropped from 302,354 to 96,326 (60%) in 1976 and 67,070 (40%) in 1977, respectively. The total catch in these two years, however, was considerably lower than in 1974-75.

Pacific Bonito:

The catch was variable, comprising 2% (1975) to 38% (1970) of total. The highest catch was in 1970 (66,683), followed in decreasing order by 1972 (60,963), 1973 (47,763) and 1976 (26,499). The lowest catch was in 1971 (5,985).

Rock Bass:

The catch was stable from 1970-1973, ranging from 27,310 to 33,871. A sharp drop occurred in 1974-75 falling to 2,283 and 109, respectively. No rock bass were reported in 1976 or 1977 catches.

Halfmoon:

The catch was very low (397, or 0.2% of total) in 1970, increasing abruptly in 1971 to 18,693 (14% of total). Otherwise it comprised 2-10% of total catch, ranging from 2,465 (1976) to 16,815 (1972). The two lowest years, aside from 1970, were 1974 (7,059 caught) and 1976 (2,465 caught).

Pacific Mackerel:

The catch was variable, ranging from 0.2% (1974) to 28% (1977) of the total for the year. Except for 1977, the catch comprised from 0.2 to 2.0% of total. The number caught between 1976-77 increased dramatically from 1,298 (0.8%) to 47,092 (25%) even though total catch for those two years remained roughly equal (153,752 in 1976 and 167,503 in 1977).

Block 740

Over all years (1970-77) highest catches:

1. rockfish
2. Pacific bonito
3. Pacific mackerel
4. sculpin
5. rock bass

Rockfish:

Rockfish dominated the catch for all years, comprising from 42% (1970) to 87% (1974) of the total. Highest catches occurred in 1973-75 (72-86%; 131,803 to 165,033). Lowest catches occurred in 1970 (43,640, or 42%) and 1977 (58,719, or 44%). In the remaining years rockfish comprised approximately 51-62% (87,862-94,947) of the total catch.

Pacific Bonito:

Catches were in excess of 20,000 in 1970 and 1972 (24,756, or 24% and 20,530, or 14%, respectively). A sharp drop occurred in 1971 to 2,792 (2% of total). In other years the catch was variable, ranging from 527 (0.3%) in 1974 to 10,283 and 11,137 (both 6%) in 1973 and 1976, respectively. The bonito catch was low (less than 4,000) in 1971, 1974, 1975, and 1977.

Pacific Mackerel:

The catch was variable, generally about 1-4% of total, except in 1971 (15,184, or 10%) and 1977 (30,940, or 23%). Sharp increases occurred from 1970 to 1971 (1,170 to 15,184) and 1976 to 1977 (3,441 to 30,940). The total catch for these years showed an increase of 30,000 from 1970 to 1971, but a decrease of 40,000 from 1976 to 1977.

Sculpin:

The catch was somewhat variable, comprising 3 to 5% of the total in 1972-76 and 8-9% of total in 1970-71 and 1977. The number caught ranged from 3,961 (1972) to 14,115 (1971). Catches in 1971 and 1975 were in excess of 11,000, relatively high in comparison to other years.

Rock Bass:

There was a steady decline in percent of total catch from 1970-77. The catch was relatively stable between 1970 and 1972 (12,871 to 19,882) at 12-13% of total. It dropped to 8,829 (5%) in 1973 and declined rapidly thereafter, with no rock bass reported in 1975 and 1977.

DISCUSSION

The total fish take by party boat anglers in the four blocks showed a great deal of variability which cannot be directly ascribed to the presence or absence of fish. Block 718 is off one of the most popular recreational boating areas, but the declining catch may reflect over-fishing, excessive sand transport in the area, or a number of other factors. The almost simultaneous steep rise in fish in block 720 off Palos Verdes began before the kelp beds were restored. (Figure 7).

In block 719, off the harbors, the trend was steeply upward to 1973-74, followed by a drop in 1975, similar to that seen in harbor populations but not elsewhere. In 1976, catch rose slightly in block 719 and then rose precipitously in 1977. Block 720 rose slightly in 1977 as well, and this rise was not seen in harbor populations.

Means were calculated for the four blocks in an attempt to get a smoother curve. The mean curve followed fairly closely the curve for block 740, farther offshore from San Pedro, except for the increase in the mean in 1977, due largely to the high peak in block 719.

In only two years did all the numbers cluster closely; in 1971, and in 1976. In 1971, drops occurred at 718 and 720, but increases occurred at 719 and 740. In 1976, the continuing drop at 718 and a steep drop at 720 coincided with a drop at 740, while only 719 rose somewhat. The net trend over the 1970-77 period was up sharply only at 719 outside the harbor; it was relatively steady at 720 and 740 and sharply down at 718.

At 719, the mean number of fish catch per hour of effort was also highest, as was the mean number of fish caught per angler and the mean number of fish per boat per day. Apparently the success of party boats had not overfished block 719 through 1977.

CONCLUSIONS ON FISH INVESTIGATIONS

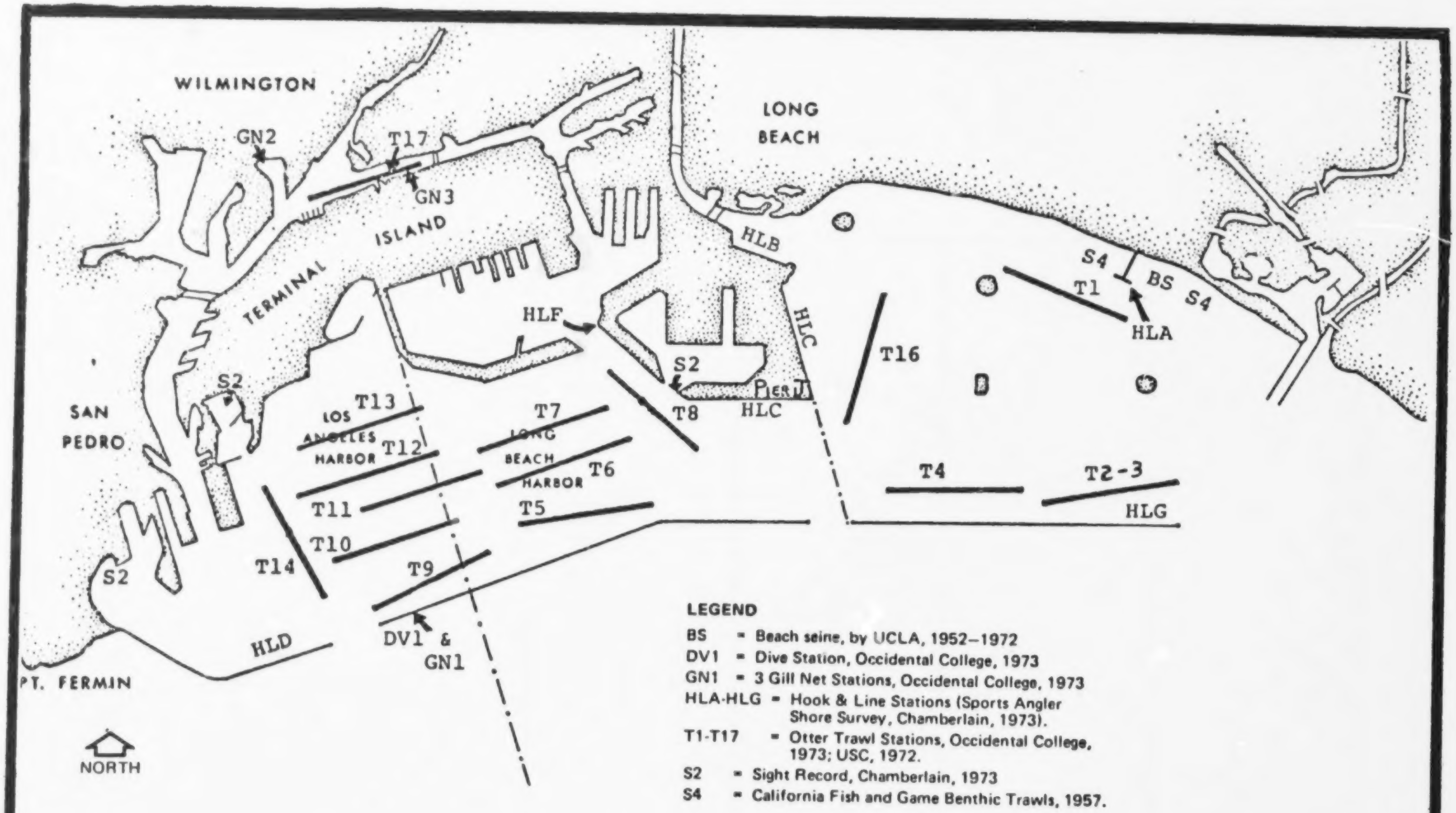
The mean number of fish per trawl in the Los Angeles-Long Beach outer harbors experienced a four-fold drop between 1973 and 1978. Although a small recovery increase occurred in 1977, it was followed by a continued drop in 1978. This contrasts with an almost two-fold increase between 1972-73 and 1977 in party boat catch in the area outside the harbor, which was interrupted by small decreases in 1975-76.

There is no indication that cessation of cannery discharges has been beneficial to harbor fish populations; rather, it appears that the change has been detrimental. However, it is impossible to state at this time that cessation is the *only* cause of the large decrease because of the many unknowns. The 1973-74 drop preceded in time the 1975 installation of DAF treatment of cannery wastes. The precipitous drop in December 1977 coincided with cessation of cannery effluents and diversion of wastes to TITP secondary treatment. The July 1978 peak return of fish to the harbor coincided with the peak period of TITP malfunction during which large amounts of BOD and suspended solids were released to the entire central outer harbor.

The two important fish species were particularly affected. White croaker, which dropped 10- to 20-fold over the 1973-78 period, was the principal fish caught by low income shore anglers. Anchovy dropped by a factor of perhaps 100-fold in the harbor in the same period. This may be responsible in part for the large drop in gull species in the harbor, which fed on anchovies and fish "gurry" (floating protein-fat coagulates). The offshore anchovy spawning biomass, which was the highest in 1973-75, has experienced about a four-fold decrease since then and in 1979 is at the lowest since acoustical records have been kept (Table 18).

The TITP sewage outfall now seems to be the only nutrient area left in the harbor that shows increased fish populations, as compared with other trawl stations. It is therefore very important to maintain the now small fish population in the harbor.

LITERATURE CITED: See Section VI.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T1
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PEDRO
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T9
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T6
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T4
T2-3
HLG
HLD
DV1
&
GN1
PT. FERMIN
NORTH
LEGEND
BS = Beach seine, by UCLA, 1952–1972
DV1 = Dive Station, Occidental College, 1973
GN1 = 3 Gill Net Stations, Occidental College, 1973
HLA-HLG = Hook & Line Stations (Sports Angler Shore Survey, Chamberlain, 1973).
T1-T17 = Otter Trawl Stations, Occidental College, 1973; USC, 1972.
S2 = Sight Record, Chamberlain, 1973
S4 = California Fish and Game Benthic Trawls, 1957.

Source: Chamberlain, 1973

Figure 1

LOCATION OF LOS ANGELES–LONG BEACH HARBOR FISH SURVEYS TO 1974

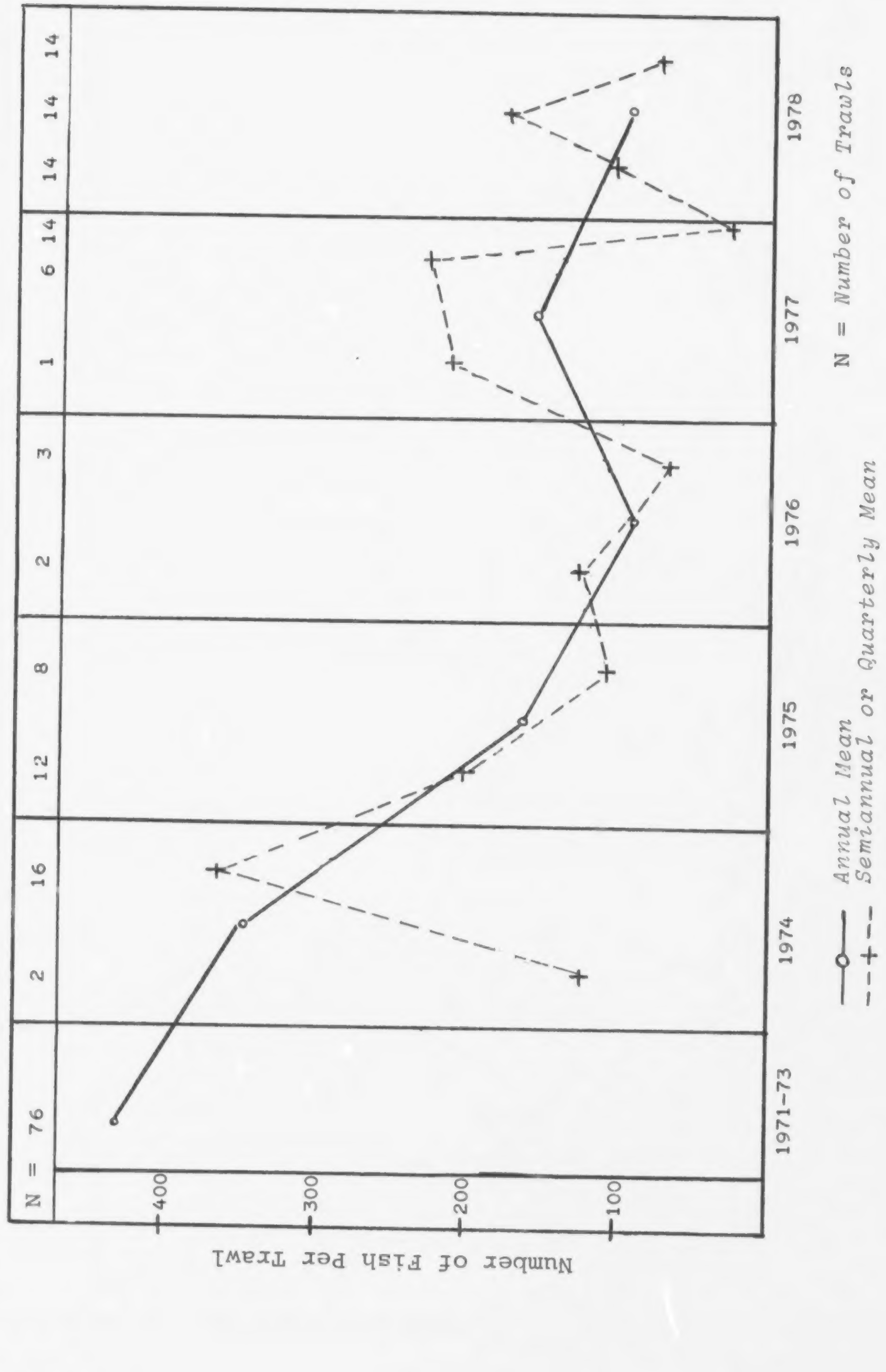

Figure 2. Mean Number of Fish Per Trawl in Outer Los Angeles Harbor, 1971-1978.

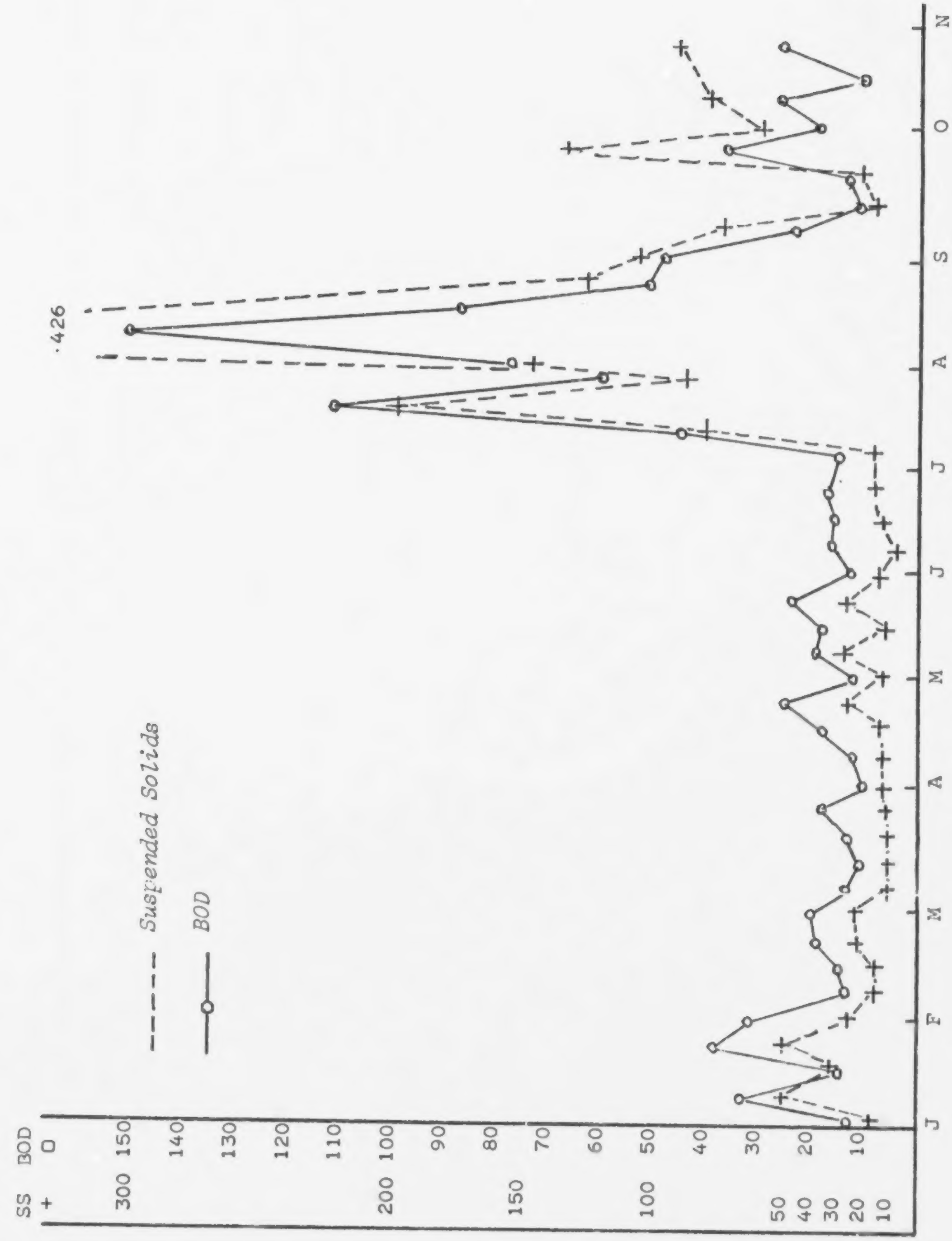

Figure 3. 7-Day Averages of TIT fluent Suspended Solids and BOD, 1978, in mg/l. Chlorination Feb.-August. Plant Malfunction June-August.

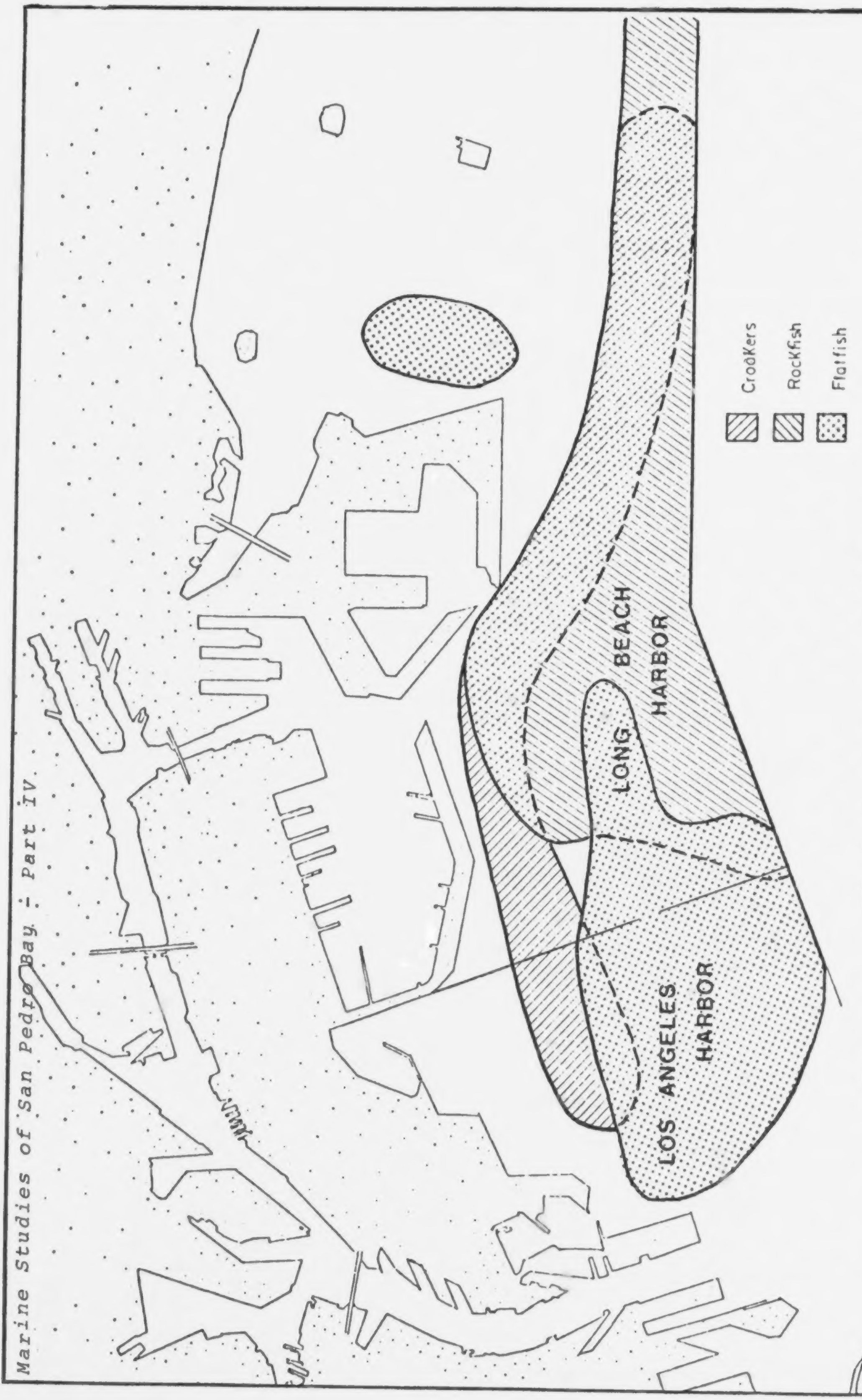

Figure 4. Distributional Pattern of Fishes in L.A. Harbor, 1972-73

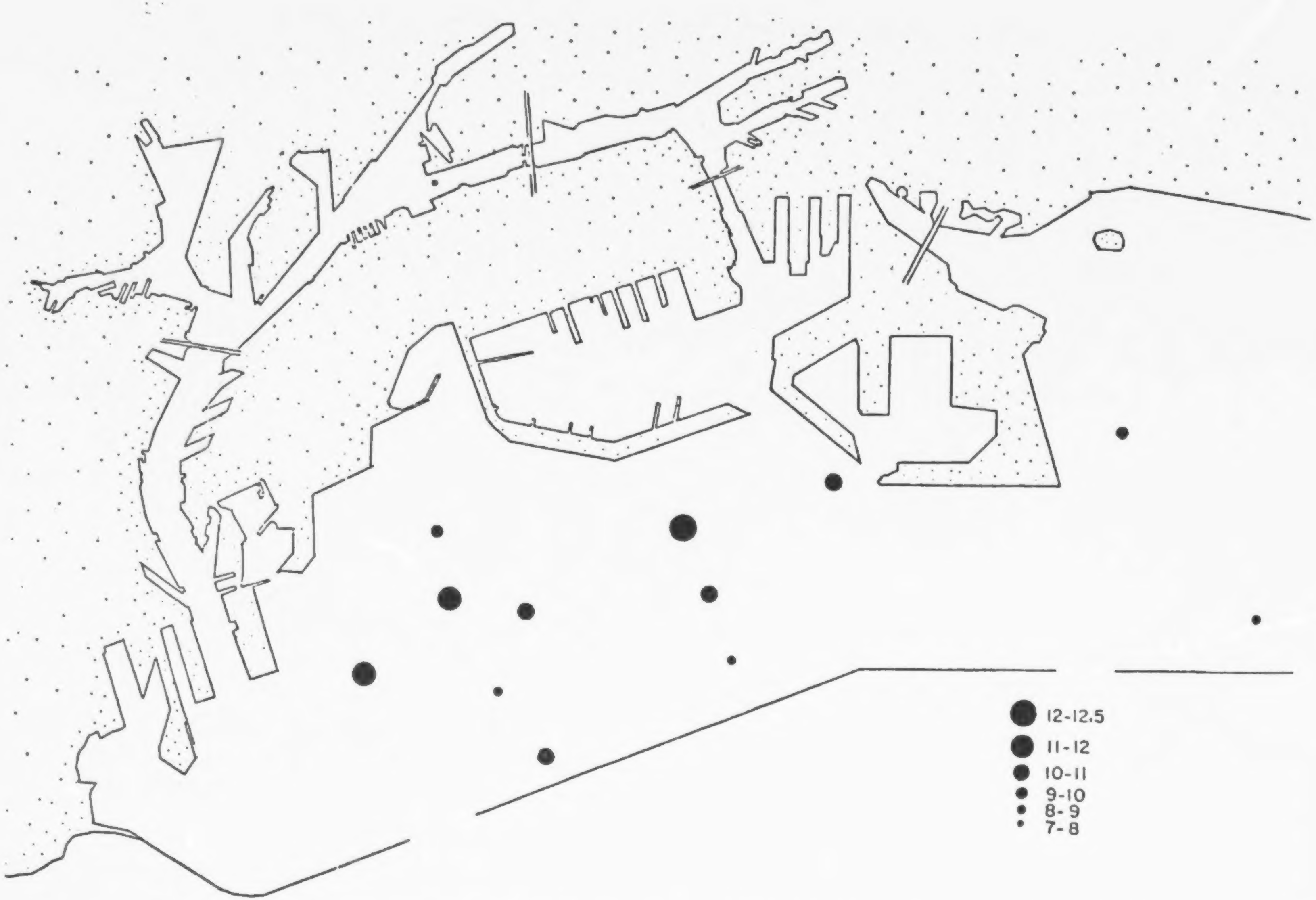

Figure 5. Mean Number of Fish Species, 1972-73 (Stephens et al., 1974)

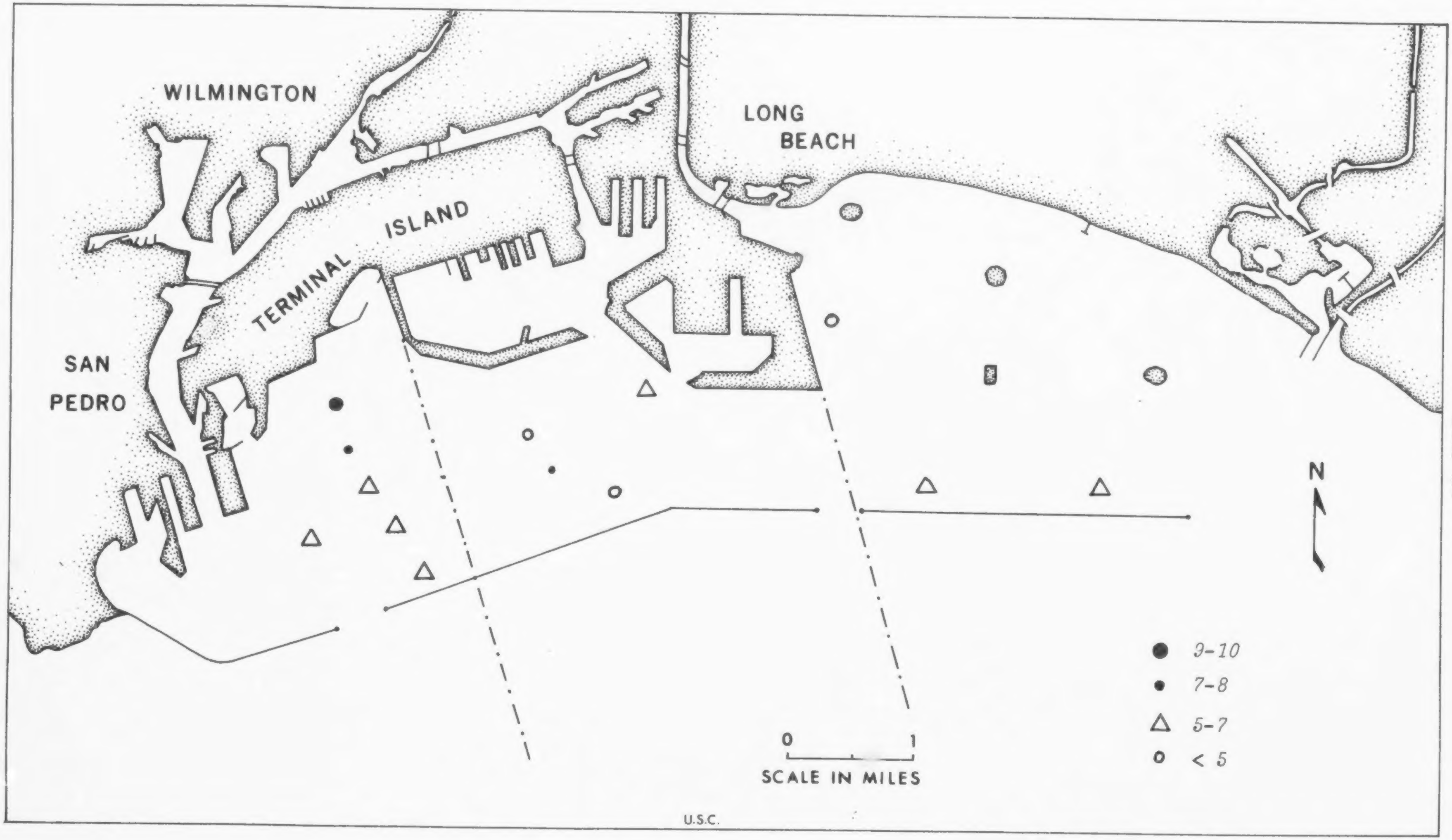

Figure 6. Mean Number of Fish Species by Station, 1978

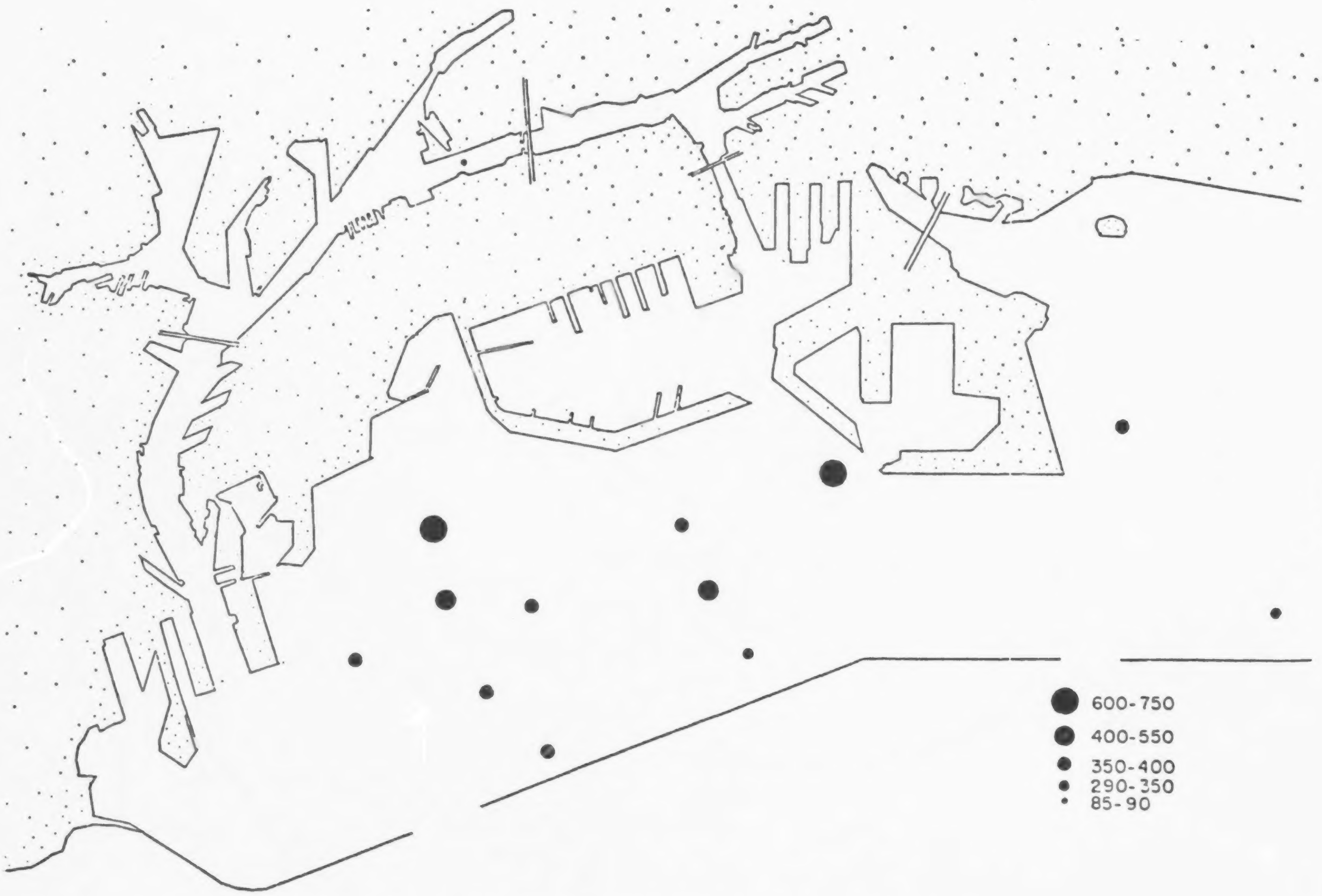

Figure 7. Mean Fish Trawl Abundances, 1972-73

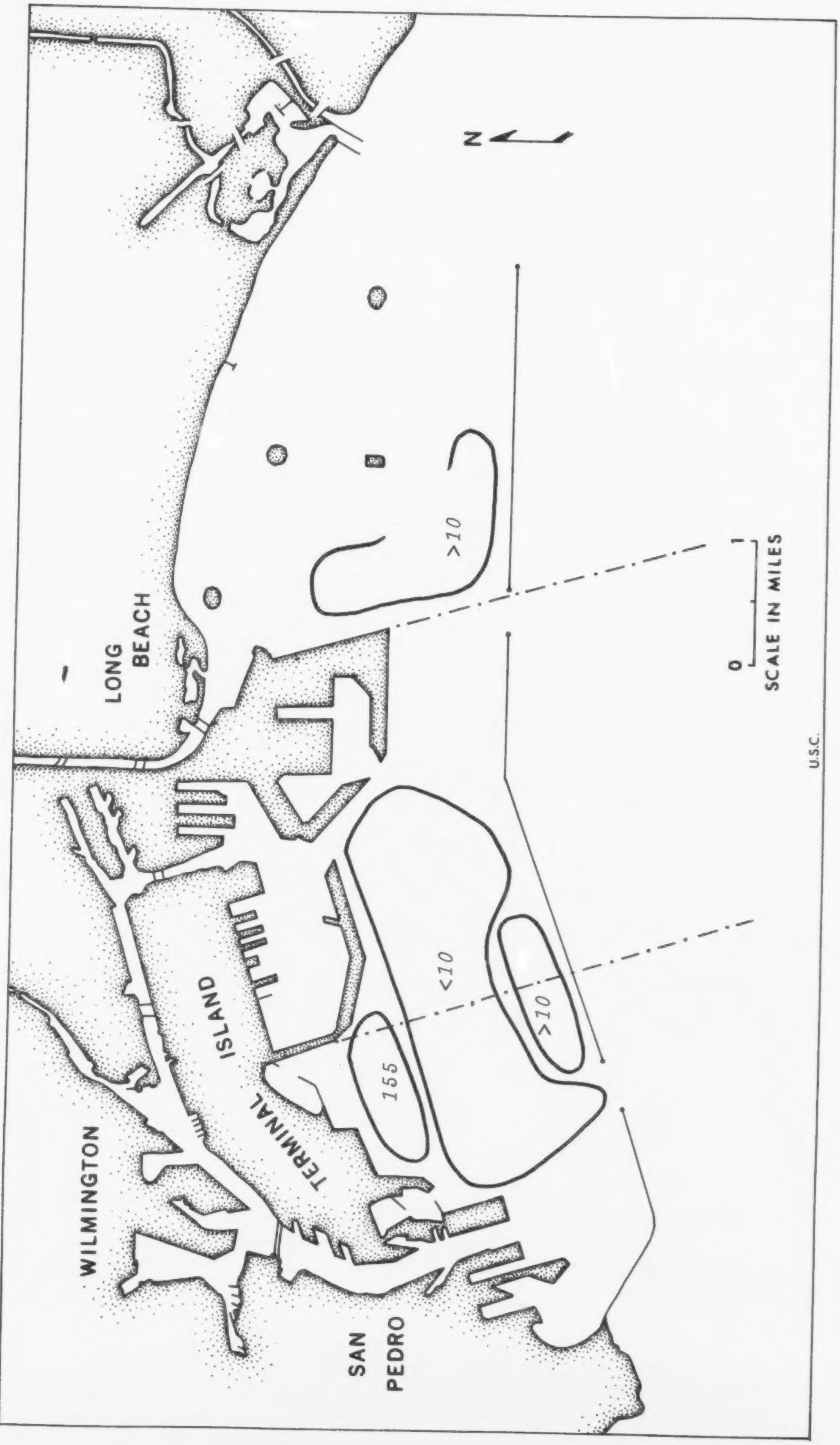

Figure 8. Mean Fish Trawl Abundances, December 1977

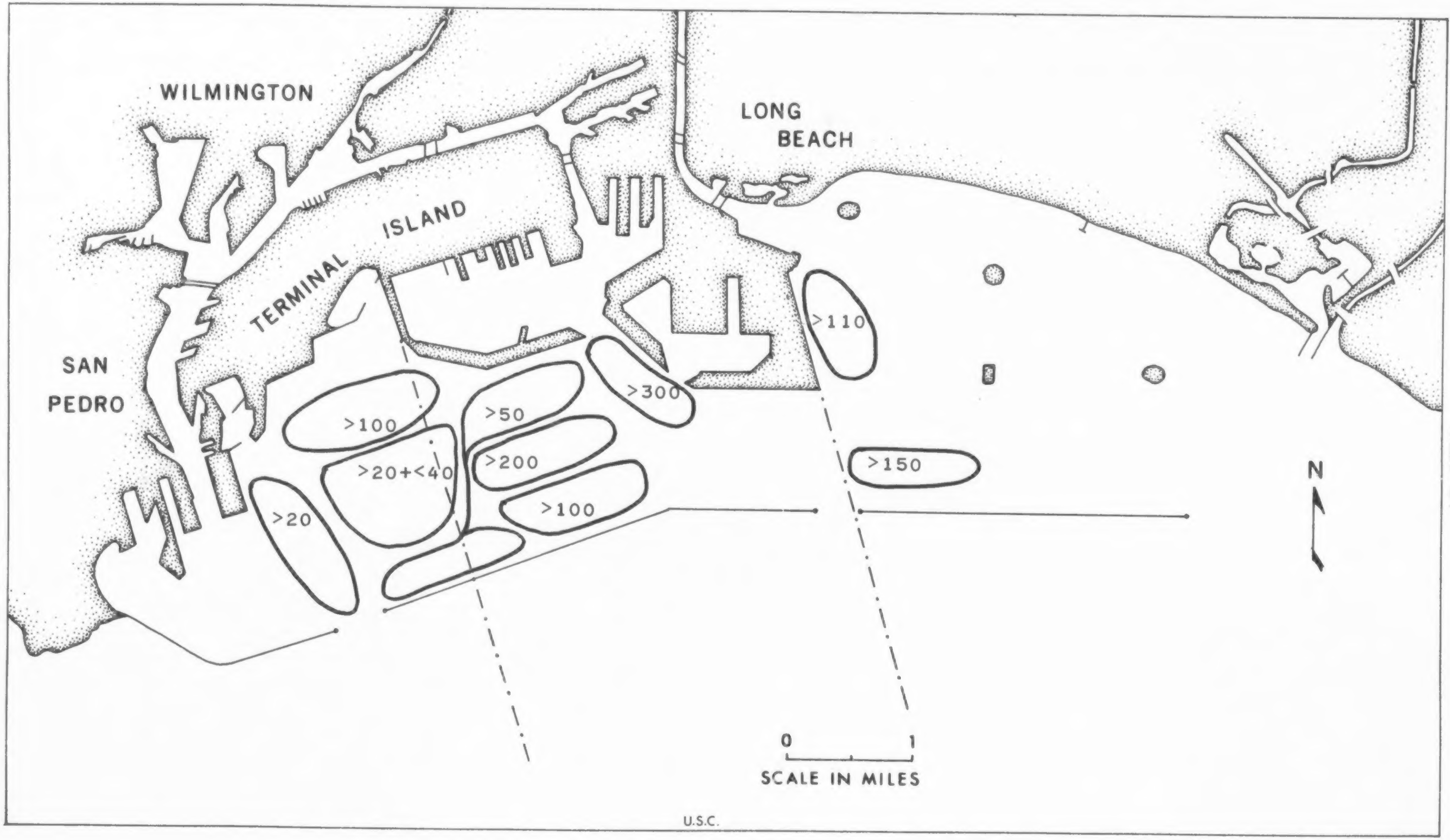

Figure 9. Mean Fish Trawl Abundances, April 1978

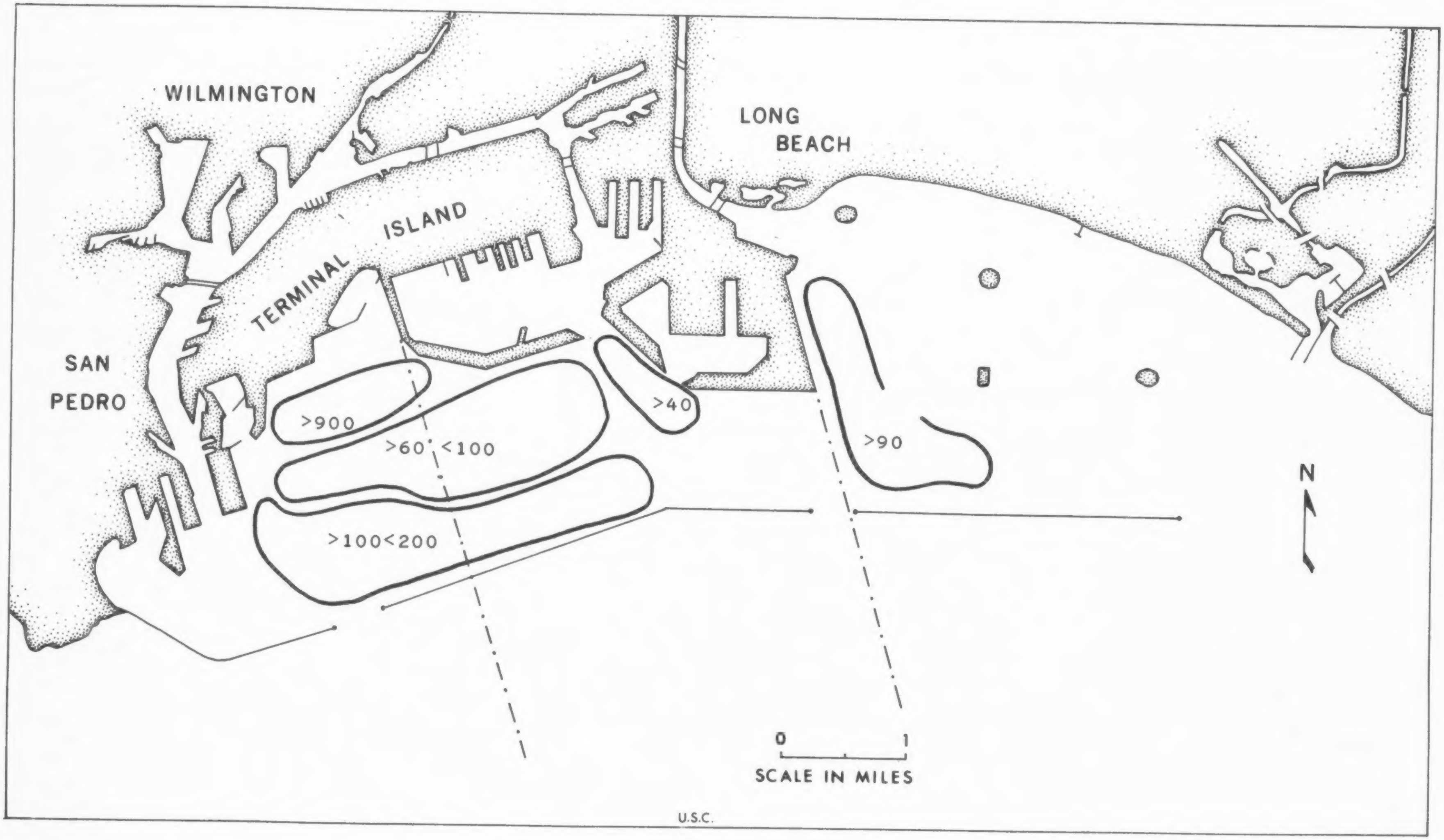

Figure 10. Mean Fish Trawl Abundances, July 1978

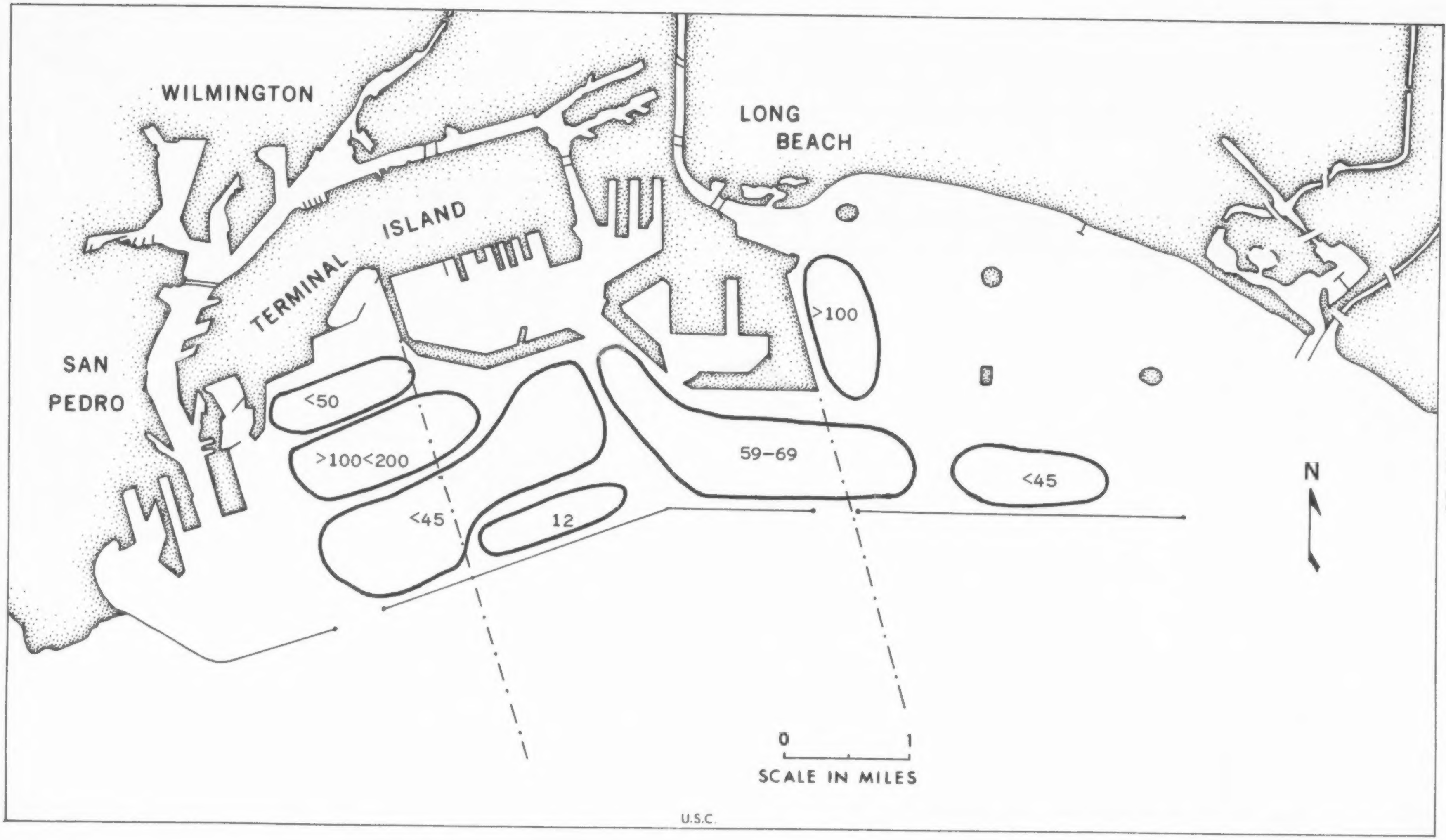

Figure 11. Mean Fish Trawl Abundances, October 1978

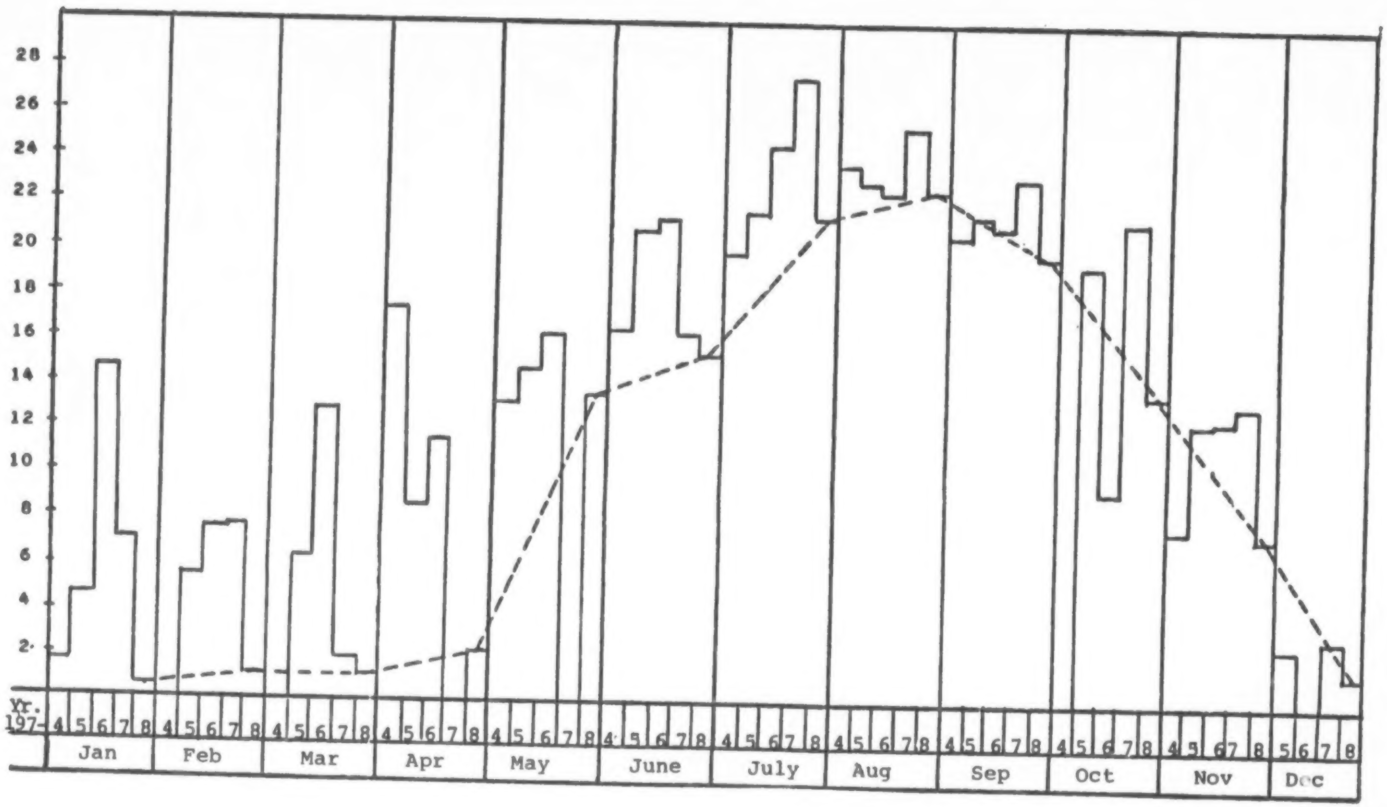

Figure 12. A Live Bait Boat Catch 1974-1978 (Dashed line is 1978 curve)
Units in 1,000's of scoops. 1 scoop = 12.5 lbs. of anchovy

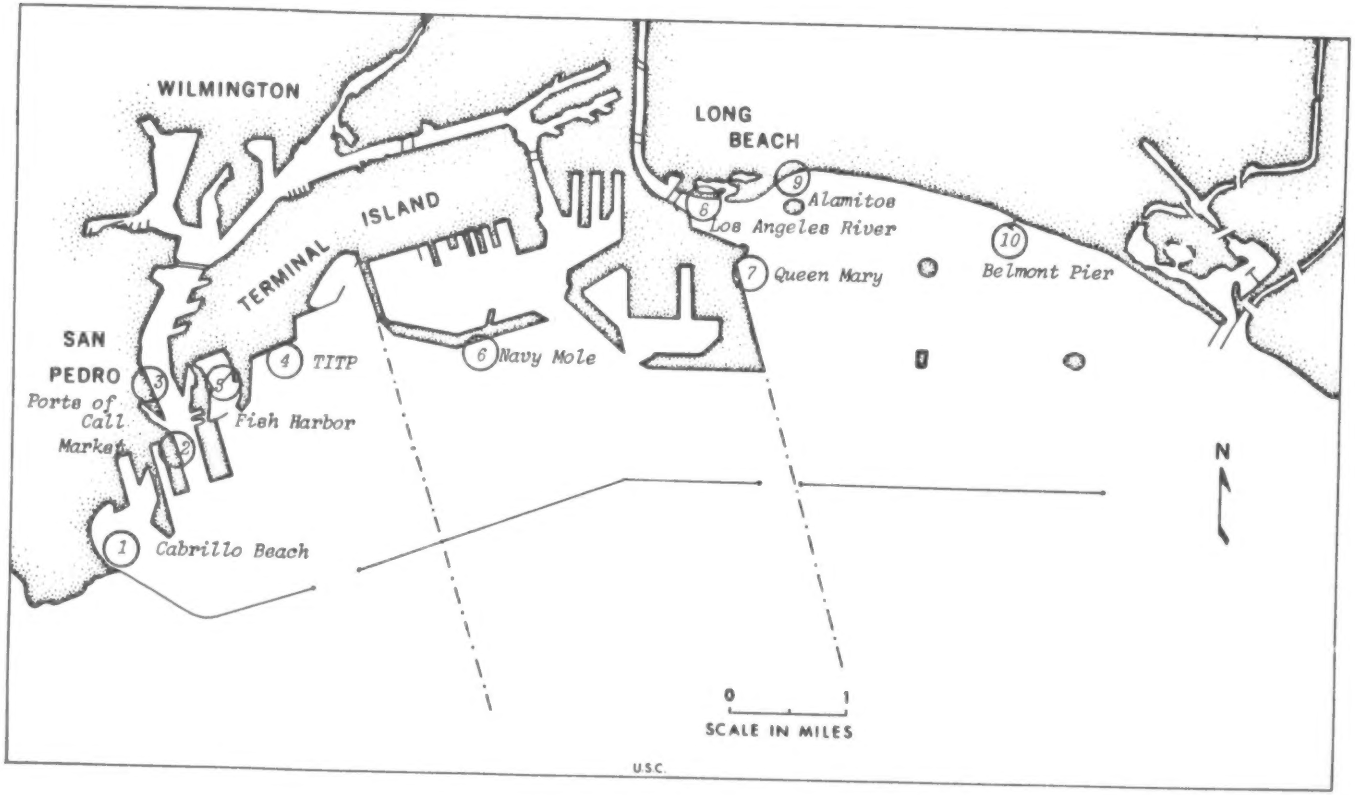

Figure 13. Sampling Areas for Creel Census

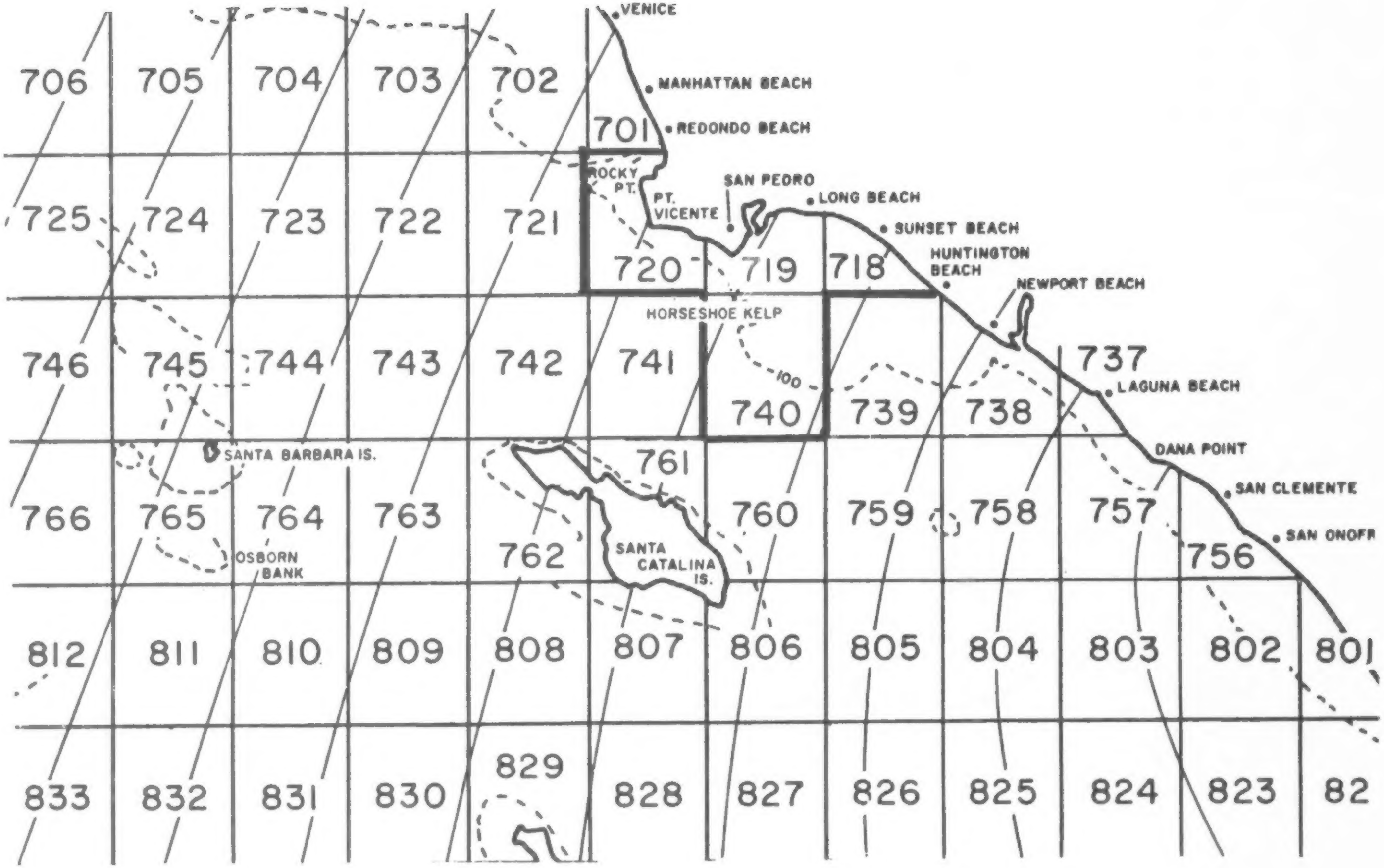

Figure 14. Party Boat Catch Analysis for Blocks 718, 719, 720 and 740.

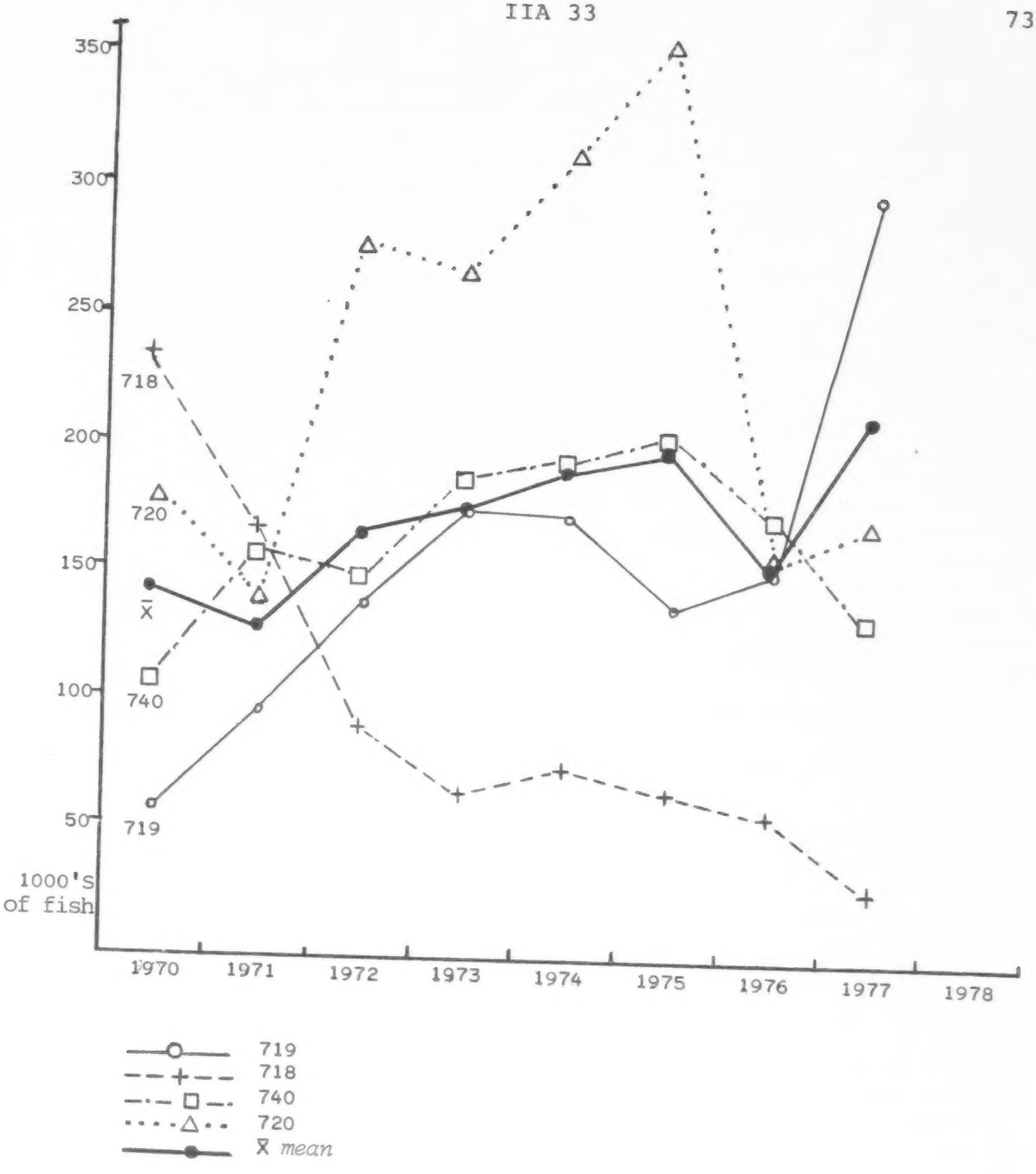

Figure 15. Total Party Boat Catches by Year, by Block and Mean of Four Blocks

Table 1. Harbor Trawl Data, 1971-1978.

SPECIES	1971-73	1974 J-J	1974 J-D	1975 J-J	1975 J-D	1976 J-J	1976 J-D
Engraulis mordax	9871	–	286	2	110	–	51
Symphurus atricauda	5102	99	580	760	198	67	24
Genyonemus lineatus	4697*	20	4069	671	44	6	47
Citharichthys stigmaeus	3723	43	547	679	114	97	10
Seriphus politus	2172	1	57	30	63	–	2
Cymatogaster aggregata	2148	3	30	2	39	1	6
Phanerodon furcatus	2111	43	125	61	68	36	40
Porichthys myriaster	411	6	5	5	1	–	–
Lepidogobius lepidus	412	7	42	31	6	1	2
Sebastes miniatus	339	–	–	–	–	–	–
Pleuronichthys verticalis	283	19	57	83	15	3	3
Anchoa delicatissima	201	–	1	1	–	–	–
Anchoa compressa	85	–	5	–	–	–	–
Pleuronichthys decurrens	80	–	3	4	–	–	–
Sebastes serranoides	79	–	–	–	–	–	–
Embiotoca jacksoni	63	2	20	19	3	9	3
Sebastes paucispinis	45	–	–	–	–	–	–
Sebastes saxicola	59	–	–	–	–	–	–
Synodus lucioceps	34	–	14	3	–	1	–
Parophrys vetulus	31	1	5	9	1	–	–
Hyperprosopon argenteum	29	–	5	1	–	–	–
Rhacochilus sp.	23	–	–	–	–	–	–
Paralichthys californicus	22	–	26	28	4	9	2
Syngnathus sp.	18	–	–	–	–	–	–
Odontopyxis trispinosa	15	–	6	–	–	–	–
Chilara taylori	12	–	–	–	–	–	–
Sebastes dalli	–	1	–	3	171	9	–
Sebastes auriculatus	1	–	13	–	1	–	–
Xystreurys liolepis	7	–	2	1	–	2	–
Peprilus simillimus	–	–	2	–	2	–	5
Zaniolepis frenata	–	–	1	–	–	–	–
Clevelandia ios	–	–	1	–	–	–	–
Pleuronichthys ritteri	–	1	–	–	–	–	–
Neoclinus uninotatus	1	–	1	4	1	–	–
Paralabrax maculatofasciatus	1	–	1	–	–	–	–
Paralabrax nebulifer	2	–	1	1	–	–	–
Rhinobatus productus	–	–	1	–	–	–	–
Squalus acanthias	6	–	1	2	–	–	–
Scorpaena guttata	6	1	–	3	–	–	–
Hypsopsetta guttulata	9	–	–	2	–	5	–
Myliobatis californica	2	–	–	1	–	–	–
Atherinops affinis	–	–	–	1	–	–	–
Leuresthes tenuis	–	–	–	1	–	–	–
Hippoglossina stomata	5	–	–	–	–	1	–
Amphistichus argenteus	–	–	–	–	–	–	–
Urolophus halleri	–	–	–	–	–	–	–
Gymnura marmorata	–	–	–	–	–	–	–
Torpedo californica	3	–	–	1	–	–	–
N = No. of Trawls	76	2	16	12	8	2	3
$\bar{x}$		126.0	369.6	201.2	102.6	124.5	65.0
Annual $\bar{\bar{x}}$	423.2	342.0		161.8		88.8	

1971-77 $\bar{x}$ = 351.2 n = 126

* Not including 25,487 juveniles collected summer 1973

Table 1 (cont.)

SPECIES	1977		'77	1978		
	J-J	J-N	DEC	APR	JUL	OCT
Engraulis mordax	-	193	6	-	114	14
Symphurus atricauda	78	165	60	462	533	369
Genyonemus lineatus	57	725	209	887	1391	328
Citharichthys stigmaeus	7	9	19	39	234	69
Seriphus politus	19	97	6	44	65	137
Cymatogaster aggregata	-	3	-	11	3	-
Phanerodon furcatus	41	11	21	11	38	4
Porichthys myriaster	-	2	-	4	20	1
Lepidogobius lepidus	4	2	2	3	-	16
Sebastes miniatus	-	-	-	-	-	-
Pleuronichthys verticalis	1	2	5	3	12	2
Anchoa delicatissima	-	-	-	-	-	-
Anchoa compressa	-	1	-	-	-	-
Pleuronichthys decurrens	-	-	-	-	-	-
Sebastes serranoides	-	-	-	-	-	-
Embiotoca jacksoni	-	2	6	5	7	-
Sebastes paucispinis	-	-	-	-	-	-
Sebastes saxicola	-	-	-	-	-	-
Synodus lucioceps	-	2	25	26	18	3
Parophrys vetulus	-	-	-	-	-	1
Hyperprosopon argenteum	-	-	1	28	3	-
Rhacochilus sp.	1	-	-	-	3	-
Paralichthys californicus	-	4	9	8	12	4
Syngnathus sp.	-	-	-	-	3	-
Odontopyxis trispinosa	-	-	-	-	-	-
Chilara taylori	-	-	1	1	3	1
Sebastes dalli	-	136	-	24	4	1
Sebastes auriculatus	-	-	-	-	-	2
Xystreurys liolepis	-	-	1	-	8	1
Peprilus simillimus	-	-	-	1	3	3
Zaniolepis frenata	-	-	-	-	-	-
Clevelandia ios	-	-	-	-	-	-
Pleuronichthys ritteri	-	-	-	-	-	-
Neoclinus uninotatus	-	-	-	-	-	-
Paralabrax maculatofasciatus	-	-	1	-	-	-
Paralabrax nebulifer	-	-	-	-	-	2
Rhinobatus productus	-	-	-	-	-	-
Squalus acanthias	-	-	-	-	-	-
Scorpaena guttata	-	-	-	-	3	1
Hypsopsetta guttulata	-	-	1	1	3	-
Myliobatis californica	-	-	-	-	-	-
Atherinops affinis	-	-	-	-	-	-
Leuresthes tenuis	-	-	-	-	-	-
Hippoglossina stomata	-	-	-	-	-	-
Amphistichus argenteus	-	-	-	3	-	-
Urolophus halleri	-	-	-	1	-	-
Gymnura marmorata	-	-	1	-	-	-
Torpedo californica	-	-	-	-	-	-
N = No. of Trawls	1	6	14	15	13	13
$\bar{x}$	208.0	225.8	26.7	104.1	174.0	73.8

1977-78 $\bar{x}$ = 93.8 n = 55

Table 1 (cont.)

SPECIES	1971-11/77	12/77-10/78	GRAND TOTAL 1971-78
Engraulis mordax	10,513	134	10,647
Symphurus atricauda	7,073	1424	8,497
Genyonemus lineatus	10,336	2815	13,151*
Citharichthys stigmaeus	5,229	361	5,590
Seriphus politus	2,441	252	2,693
Cymatogaster aggregata	2,232	14	2,246
Phanerodon furcatus	2,536	74	2,610
Porichthys myriaster	466	25	491
Lepidogobius lepidus	507	21	528
Sebastes miniatus	339	-	339
Pleuronichthys verticalis	468	22	490
Anchoa delicatissima	203	-	203
Anchoa compressa	91	-	91
Pleuronichthys decurrens	87	-	87
Sebastes serranoides	79	-	79
Embiotoca jacksoni	121	18	139
Sebastes paucispinis	45	-	45
Sebastes saxicola	59	-	59
Synodus lucioceps	54	72	126
Parophrys vetulus.	47	-	48
Hyperprosopon argenteum	35	32	67
Rhacochilus sp.	24	3	27
Paralichthys californicus	95	33	128
Syngnathus sp.	18	3	21
Odontopyxis trispinosa	21	-	21
Chilara taylori	12	6	18
Sebastes dalli	320	30	350
Sebastes auriculatus	15	2	17
Xystreurys liolepis	12	10	22
Peprilus simillimus	9	7	16
Zaniolepis frenata	1	-	1
Clevelandia ios	1	-	1
Pleuronichthys ritteri	1	-	1
Neoclinus uninotatus	7	-	7
Paralabrax maculatofasciatus	2	1	3
Paralabrax nebulifer	4	2	6
Rhinobatus productus	1	-	1
Squalus acanthias	9	-	9
Scorpaena guttata	10	-	14
Hypsopsetta guttulata	16	5	21
Myliobatis californica	3	-	3
Atherinops affinis	1	-	1
Leuresthes tenuis	1	-	1
Hippoglossina stomata	6	-	6
Amphistichus argenteus	0	-	3
Urolophus halleri	0	1	1
Gymnura marmorata	0	1	1
Torpedo californica	4	-	4

*(+25,487 juveniles = 38,638)

Table 2. Important Species Taken in July 1978 Harbor Trawls.

Species	Station Number													x̄	S.D.
	2-3	4	5	6	7	8	9	10	11	12	13	14	16		
Genyonemus	16	34	69	60	3	28	114	10	16	10	774	1	162	107	215
Symphurus	70	61	53	22	63	10	39	29	53	30	4	48	57	41	21
Citharichthys	1	1		1			27	50	50	11		89	2	18	28
Seriphus			6	2		1	1				50		10	5	14
Synodus		2	2	3		1			3	3		1	3	1.4	1.3
Sebastes dalli		1	2	1										0.3	0.6
Phanerodon	3	2		1	1		2	9	1	12	6		1	2.9	3.8
Porichthys myriaster	3	1	6	1	2		1			1				1.5	1.7
Paralichthys			1	2			2	1		2	1	2		0.9	0.9
Pleuronichthys verticalis				2	1			3				5	1	0.9	1.6
Cymatogaster						1					1			0.2	0.4
Rhacochilus vacca	1					1							1	0.2	0.4
Embiotoca	1							1	1	2	2			0.5	0.8
Engraulis		4					1			11	92		6	8.8	25.2
Peprilus	1			1										0.2	0.4
Chilara							1		1					0.2	0.4
Xystreurys								2		2	1	2	1	0.6	0.9
Hyperprosopon										1			1	0.2	0.4
Hypsopsetta										1		1		0.2	0.4
Syngnathus											2			0.2	0.6
Scorpaena												2		0.2	0.6

Table 3. Harbor Trawl Data for October 1978.

Species	3	4	5	6	7	8	9	10	11	12	13	14	15	16	TOTAL
Symphurus atricauda	38	59	9	20	20	54	28	22	27	5	2	13	--	72	369
Genyonemus lineatus	4	8	1	2	8	0	1	7	46	61	24	1	--	165	328
Seriphus politus	0	1	0	0	2	0	0	0	17	99	0	0	--	18	137
Citharichthys stigmaeus	0	0	1	4	1	0	6	14	24	0	0	19	--	0	59
Lepidogobius lepidus	0	0	0	5	7	2	0	1	0	1	0	0	--	1	16
Engraulis mordax	0	0	0	0	0	0	0	0	2	5	7	0	--	2	14
Phanerodon furcatus	1	0	0	0	0	0	0	0	0	1	1	0	--	1	4
Paralichthys californicus	0	0	0	0	0	0	0	0	2	1	1	0	--	0	4
Peprilus simillimus	0	0	0	0	0	0	0	0	1	0	2	0	--	0	3
Synodus lucioceps	1	0	0	0	0	0	0	0	0	0	0	1	--	1	3
Paralabrax nebulifer	0	1	0	1	0	0	0	0	0	0	0	0	--	0	2
Pleuronichthys verticalis	0	0	0	0	1	1	0	0	0	0	0	0	--	0	2
Sebastes auriculatus	0	0	0	0	0	1	0	0	0	0	0	1	--	0	2
Sebastes dalli	0	0	0	1	1	0	0	0	0	0	0	0	--	0	2
Chilara taylori	0	0	0	0	0	1	0	0	0	0	0	0	--	0	1
Parophrys vetulus	0	0	0	1	0	0	0	0	0	0	0	0	--	0	1
Porichthys myriaster	0	0	0	0	0	0	1	0	0	0	0	0	--	0	1
Scorpaena guttata	0	0	1	0	0	0	0	0	0	0	0	0	--	0	1
Xystreurys liolepis	0	0	0	0	0	0	0	0	1	0	0	0	--	0	1
TOTAL	44	69	12	34	40	59	36	44	120	173	37	35	--	260	960

Table 4. Number of Fish/Trawl and Number of Species/Trawl
Outer Los Angeles Harbor, December 1977-October 1978

Sta. #	Number/trawl				Species/trawl			
	12/77	4/78	7/78	10/78	12/77	4/78	7/78	10/78
2-3	25	34	95	44	5	4	7	4
4	15	155	107	69	3	6	9	4
5	2	108	139	12	2	3	8	4
6	9	216	96	34	4	7	11	7
7	1	70	70	40	1	5	5	7
8	6	306	42	59	3	9	6	5
9	13	57	187	36	2	8	9	4
10	7	28	105	44	4	10	8	5
11	14	31	126	108	5	6	7	8
12	4	22	87	183	2	8	13	7
13	155	125	990	40	9	10	12	7
14	7	16	151	33	3	6	9	5
16 (1)	2	121	60	111	1	4	11	5
16 (2)	-	116	186	161	-	4	5	6
$\bar{x}$ =	20.0	104.0	174.0	69.6	3.4	6.5	8.6	5.6
S.D. =	41.0	81.9	238.0	51.6	2.1	2.2	2.3	5

Table 5. Once-a-month Survey of Numbers of Fish Caught per Angler Rod.

Station	1 Cabrillo Beach	2 San Pedro Markets	3 Ports O'Call	4 Outfall Area	5 Fish Harbor	6 Navy Mole	7 Queen Mary	8 Los Angeles River	9 Alamitos Blvd.	10 Belmont Beach
January	0.63	5.33	1.00	0	1.09	1.02	0.78	0.47	1.58	0.94
February	0.39	2.00	0.20	0.13	0.83	0.44	1.60	0.11	1.14	1.40
March	0.57	21.13	4.00	0.31	0.90	2.21	0.55	1.00	0.66	1.71
April	0.35	1.50	--	0.55	1.48	0.41	0.69	0.85	1.38	0.44
May	0.26	11.00	1.67	0.26	1.24	1.27	0.66	0.70	0.75	0.31
June	0.49	8.00	0	0.79	0.70	1.26	0.77	0.67	1.30	0.44
July	0.22	--	--	1.65	1.03	1.81	0.34	2.25	1.11	0.71
August	0.50	--	--	0.74	0.68	0.86	5.41	1.52	1.04	3.11
September	3.64	--	--	1.85	1.65	0.35	2.05	0.69	1.71	1.79
October	2.20	6.00	--	0	1.38	1.20	0.92	1.86	1.92	2.81
November	0.18	2.00	--	--	1.56	0.48	0.90	1.68	1.02	1.18
Average	0.86	7.12	1.37	0.63	1.14	0.91	1.33	1.07	1.24	1.35

These numbers represent an approximation of numbers of fish caught per angler rod for the various areas, giving an approximate indication of fishing success at each area. When accessible, San Pedro Markets were the most productive. The outfall area was one of the worst fishing spots of the sampled areas.

Table 6. January, 1978

Stations	1	2	3	4	5	6	7	8	9	10
Amphistichus argentus							2		1	
Anisotremus davidsoni										
Atherinops affinis										
Atherinopsis calif						1				4
Cheilotrema saturnam										
Cymatogaster aggregata	2	1			1	1				7
Cynoscion nobilis										
Cyprinus carpio										
Damalichthys vacca	1									1
Embiotoca jacksoni	1	10			4	39	36	7	29	11
Genyonemus lineatus	18	31	1		11		9	2	16	148
Girella nigricans		1				1	3		8	
Halichoeres semicinctus						1				
Heterostichus rostratus										
Hyperprosopon argrnteum		1								3
Hypsopsetta guttulata	1						3			
Hypsurus caryi										
Lepomis macrochirus										
Leptocottus armatus										
Medialuna californiensis							6			
Menticirrhus undulatus										
Mustelus californicus										
Myliobatis californica										
Neoclinus blanchardi						2				
Oxyjulis californica										
Paralabrax clathratus						1				
Paralabrax maculatofasciatus						1	1		1	
Paralabrax nebulifer					1	1	5		3	1
Paralichthys californicus							2			
Peprilus simmilimus										
Phanerodon furcatus	1	3			4	3	5	8	15	4
Platichthys stellatas										
Rhacochilus toxotes							1			
Rhinobatos productus										
Roncador sternsii										
Sarda chiliensia										
Scomber japonicus							1			
Scorpaena guttata										
Scorpaenichthys marmoratus							1		1	
Sebastes atrovirens					3					
Sebastes auriculatus										
Sebastes dallii										
Sebastes mystinus										
Sebastes rastrelliger					1		4		1	
Sebastes serranoides										
Seriphus politus										
Sphyraena argentea										
Squalus acanthias										
Synodus lucioceps	1	1					12		1	
Trachurus symmetricus	3						2			
Triakis semifasciata										
Tridentiger trig.										
Xystreurys liolepis										

Table 7. February, 1978

Stations	1	2	3	4	5	6	7	8	9	10
Amphistichus argentus										
Anisotremus davidsoni							1			
Atherinops affinis										
Atherinopsis calif	3	2								2
Cheilotrema saturnam										
Cymatogaster aggregata							2		1	1
Cynoscion nobilis										
Cyprinus carpio										
Damalichthys vacca				1				2		
Embiotoca jacksoni	4	6	1		13	12	7		19	3
Genyonemus lineatus			1		8		135		29	193
Girella nigricans					1		1		1	
Halichoeres semicinctus										
Heterostichus rostratus										
Hyperprosopon argrnteum									2	7
Hypsopsetta guttulata										
Hypsurus caryi						4				
Lepomis macrochirus										
Leptocottus armatus										
Medialuna californiensis										
Menticirrhus undulatus										
Mustelus californicus										
Myliobatis californica										
Neoclinus blanchardi	1								1	
Oxyjulis californica						1				
Paralabrax clathratus					1	1				
Paralabrax maculatofasciatus							2		4	
Paralabrax nebulifer	1				1		2			
Paralichthys californicus										
Peprilus simmilimus										
Phanerodon furcatus	4			1		1	3	1	1	
Platichthys stellatas										
Rhacochilus toxotes										
Rhinobatos productus										
Roncador sternsii										
Sarda chiliensia										
Scomber japonicus										2
Scorpaena guttata										1
Scorpaenichthys marmoratus										
Sebastes atrovirens										
Sebastes auriculatus							1			
Sebastes dallii							1			
Sebastes mystinus										
Sebastes rastrelliger					6					
Sebastes serranoides										
Seriphus politus										16
Sphyraena argentea										
Squalus acanthias										
Synodus lucioceps	4				3					2
Trachurus symmetricus	1									1
Triakis semifasciata										
Tridentiger triq.										
Xystreurys liolepis										

Table 8. March, 1978

Stations	1	2	3	4	5	6	7	8	9	10
Amphistichus argentus										3
Anisotremus davidsoni										
Atherinops affinis										3
Atherinopsis calif	2	8		3		2				1
Cheilotrema saturnam										
Cymatogaster aggregata							5			8
Cynoscion nobilis										
Cyprinus carpio										
Damalichthys vacca	1			1	1	4	1	1		4
Embiotoca jacksoni	4	1	16	1	18	48	25		38	4
Genyonemus lineatus	6	160				2	15	8	5	161
Girella nigricans									1	
Halichoeres semicinctus										
Heterostichus rostratus	1								2	
Hyperprosopon argrnteum										1
Hypsopsetta guttulata										37
Hypsurus caryi										
Lepomis macrochirus										
Leptocottus armatus										
Medialuna californiensis										
Menticirrhus undulatus										
Mustelus californicus										
Myliobatis californica										
Neoclinus blanchardi					1					
Oxyjulis californica						1				
Paralabrax clathratus						1	1			
Paralabrax maculatofasciatus	1									
Paralabrax nebulifer	1				3	1	1			1
Paralichthys californicus							1			
Peprilus simmilimus										
Phanerodon furcatus	22					2	7		3	38
Platichthys stellatas					1					
Rhacochilus toxotes										
Rhinobatos productus										
Roncador sternsii							2			
Sarda chiliensia										
Scomber japonicus										
Scorpaena guttata					1					
Scorpaenichthys marmoratus					2	2				
Sebastes atrovirens										
Sebastes auriculatus										
Sebastes dallii										
Sebastes mystinus										
Sebastes rastrelliger										1
Sebastes serranoides										
Seriphus politus										1
Sphyraena argentea										
Squalus acanthias						1	1			
Synodus lucioceps	3									
Trachurus symmetricus										2
Triakis semifasciata										
Tridentiger trig.										
Xystreurys liolepis										

Table 9. April, 1978

Stations	1	2	3	4	5	6	7	8	9	10
Amphistichus argentus										
Anisotremus davidsoni										
Atherinops affinis									15	
Atherinopsis calif	1			1						1
Cheilotrema saturnam										
Cymatogaster aggregata							6	1		2
Cynoscion nobilis										
Cyprinus carpio										
Damalichthys vacca	1					1		4		1
Embiotoca jacksoni	1				3	9	1	1	2	4
Genyonemus lineatus	18	3		9	29	1	30	55	28	42
Girella nigricans										
Halichoeres semicinctus										
Heterostichus rostratus									1	
Hyperprosopon argrnteum										
Hypsopsetta guttulata										5
Hypsurus caryi						2				
Lepomis macrochirus										1
Leptocottus armatus										1
Medialuna californiensis										
Menticirrhus undulatus										1
Mustelus californicus										
Myliobatis californica										
Neoclinus blanchardi										
Oxyjulis californica						1				
Paralabrax clathratus										
Paralabrax maculatofasciatus					1					
Paralabrax nebulifer	1					4	8			
Paralichthys californicus				1		3				
Peprilus simmilimus	2									
Phanerodon furcatus	5			1		2		6	1	6
Platichthys stellatas										
Rhacochilus toxotes										
Rhinobatos productus										
Roncador sternsii										
Sarda chiliensia										1
Scomber japonicus	1						2			2
Scorpaena guttata										
Scorpaenichthys marmoratus										
Sebastes atrovirens										
Sebastes auriculatus										
Sebastes dallii							2			
Sebastes mystinus										
Sebastes rastrelliger								1		
Sebastes serranoides										
Seriphus politus										
Sphyraena argentea										
Squalus acanthias										
Synodus lucioceps	3				1		1			1
Trachurus symmetricus										1
Triakis semifasciata										
Tridentiger trig.										
Xystreurys liolepis										

Table 10. May, 1978

Stations	1	2	3	4	5	6	7	8	9	10
Amphistichus argentus										
Anisotremus davidsoni										
Atherinops affinis									2	
Atherinopsis calif				1		1	1	1		4
Cheilotrema saturnam										
Cymatogaster aggregata		1								
Cynoscion nobilis										
Cyprinus carpio										
Damalichthys vacca						3				1
Embiotoca jacksoni		2	3			24	2		5	2
Genyonemus lineatus	21	40	1	7	23	1	38	37	24	39
Girella nigricans							1			
Halichoeres semicinctus										
Heterostichus rostratus										
Hyperprosopon argrnteum										1
Hypsopsetta guttulata										
Hypsurus caryi						1				
Lepomis macrochirus										
Leptocottus armatus							1			
Medialuna californiensis										
Menticirrhus undulatus							1			3
Mustelus californicus					2		1		1	
Myliobatis californica										
Neoclinus blanchardi										
Oxyjulis californica										
Paralabrax clathratus						1			3	1
Paralabrax maculatofasciatus										
Paralabrax nebulifer						3			1	
Paralichthys californicus										1
Peprilus simmilimus										
Phanerodon furcatus						3		1	5	
Platichthys stellatas										
Rhacochilus toxotes										
Rhinobatos productus										
Roncador sternsii										
Sarda chiliensia										
Scomber japonicus						4	8			4
Scorpaena guttata						1				
Scorpaenichthys marmoratus						1			1	
Sebastes atrovirens										
Sebastes auriculatus										
Sebastes dallii							1			
Sebastes mystinus							1			
Sebastes rastrelliger						2	1			
Sebastes serranoides						1				
Seriphus politus					1		1			8
Sphyraena argentea										
Squalus acanthias										
Synodus lucioceps	2	1	1			1	3	1		
Trachurus symmetricus										
Triakis semifasciata										
Tridentiger trig.										
Xystreurys liolepis										

Table 11. June, 1978

Stations	1	2	3	4	5	6	7	8	9	10
Amphistichus argentus	1									
Anisotremus davidsoni										
Atherinops affinis										
Atherinopsis calif		3			1	2	4		3	40
Cheilotrema saturnam										
Cymatogaster aggregata							3		2	11
Cynoscion nobilis										
Cyprinus carpio										
Damalichthys vacca	1							1	1	1
Embiotoca jacksoni	2	2		3	2	9	6	8	6	1
Genyonemus lineatus	29	34		8	13	20	36	24	35	41
Girella nigricans						1				
Halichoeres semicinctus										
Heterostichus rostratus									1	
Hyperprosopon argrnteum										
Hypsopsetta guttulata										4
Hypsurus caryi							2			
Lepomis macrochirus										
Leptocottus armatus										
Medialuna californiensis										
Menticirrhus undulatus										
Mustelus californicus										
Myliobatis californica										
Neoclinus blanchardi										
Oxyjulis californica							1			
Paralabrax clathratus						1				
Paralabrax maculatofasciatus							1			
Paralabrax nebulifer					1	2			2	
Paralichthys californicus				1		2				2
Peprilus simmilimus										
Phanerodon furcatus	2	1		3	2	6	3	2	6	10
Platichthys stellatas										
Rhacochilus toxotes										
Rhinobatos productus										
Roncador sternsii										
Sarda chiliensia							2			9
Scomber japonicus	8					4	12			5
Scorpaena guttata							1			1
Scorpaenichthys marmoratus										
Sebastes atrovirens										
Sebastes auriculatus										
Sebastes dallii						1				
Sebastes mystinus							1			
Sebastes rastrelliger										
Sebastes serranoides						2	2			
Seriphus politus										9
Sphyraena argentea										
Squalus acanthias										
Synodus lucioceps	4					3	10			
Trachurus symmetricus	2									1
Triakis semifasciata										
Tridentiger trig.										
Xystreurys liolepis										

Table 12. July, 1978

Stations	1	2	3	4	5	6	7	8	9	10
Amphistichus argentus										
Anisotremus davidsoni										
Atherinops affinis										
Atherinopsis calif	1									1
Cheilotrema saturnam						1	1	1		4
Cymatogaster aggregata	5							1		
Cynoscion nobilis										2
Cyprinus carpio										
Damalichthys vacca								1		
Embiotoca jacksoni	4									1
Genyonemus lineatus	2				5	11				3
Girella nigricans				33	43	40	16	86	14	116
Halichoeres semicinctus										
Heterostichus rostratus										
Hyperprosopon argrnteum	1					2				
Hypsopsetta guttulata										
Hypsurus caryi						1				
Lepomis macrochirus					2					
Leptocottus armatus										
Medialuna californiensis										
Menticirrhus undulatus										
Mustelus californicus										
Myliobatis californica										
Neoclinus blanchardi										
Oxyjulis californica										
Paralabrax clathratus							1			
Paralabrax maculatofasciatus						5			1	1
Paralabrax nebulifer									1	
Paralichthys californicus	1					3				1
Peprilus simmilimus	1					1			2	1
Phanerodon furcatus	1									
Platichthys stellatas						4				4
Rhacochilus toxotes										
Rhinobatos productus										
Roncador sternsii										1
Sarda chiliensia										
Scomber japonicus										
Scorpaena guttata S	1					2			3	
Scorpaenichthys marmoratus					1	3		1		
Sebastes atrovirens						1				
Sebastes auriculatus										
Sebastes dallii	1					1				
Sebastes mystinus										
Sebastes rastrelliger										
Sebastes serranoides						1				
Seriphus politus										
Sphyraena argentea										58
Squalus acanthias										1
Synodus lucioceps										
Trachurus symmetricus							1			4
Triakis semifasciata										
Tridentiger trig.										
Xystreurys liolepis										

Table 13. August 1978

Stations	1	2	3	4	5	6	7	8	9	10
Amphistichus argentus	1									
Anisotremus davidsoni										
Atherinops affinis				4		2	1		8	1
Atherinopsis calif	1			1		1	1			1
Cheilotrema saturnam										1
Cymatogaster aggregata	3			2						
Cynoscion nobilis										
Cyprinus carpio										
Damalichthys vacca										
Embiotoca jacksoni	1			3	2	1			17	3
Genyonemus lineatus	20			5	15	8	563	66	38	96
Girella nigricans					2	1			3	
Halichoeres semicinctus										
Heterostichus rostratus									1	
Hyperprosopon argrnteum										3
Hypsopsetta guttulata										
Hypsurus caryi										
Lepomis macrochirus										
Leptocottus armatus										
Medialuna californiensis										
Menticirrhus undulatus				1						
Mustelus californicus	1									
Myliobatis californica										
Neoclinus blanchardi										
Oxyjulis californica										
Paralabrax clathratus	1					2				
Paralabrax maculatofasciatus										1
Paralabrax nebulifer	1			1		3			3	2
Paralichthys californicus	1							1		
Peprilus simmilimus	2									3
Phanerodon furcatus	2			2						5
Platichthys stellatas										
Rhacochilus toxotes										
Rhinobatos productus									1	2
Roncador sternsii										
Sarda chiliensia										
Scomber japonicus						1		1		1
Scorpaena guttata										
Scorpaenichthys marmoratus										
Sebastes atrovirens										
Sebastes auriculatus										
Sebastes dallii	1									
Sebastes mystinus										
Sebastes rastrelliger										
Sebastes serranoides										
Seriphus politus	10						6		3	774
Sphyraena argentea										
Squalus acanthias										2
Synodus lucioceps										
Trachurus symmetricus										1
Triakis semifasciata				1						
Tridentiger trig.										
Xystreurys liolepis										1

Table 14. September, 1978

Stations	1	2	3	4	5	6	7	8	9	10
Amphistichus argentus										
Anisotremus davidsoni										
Atherinops affinis									1	1
Atherinopsis calif	3			3			4	1		
Cheilotrema saturnam	1				1				1	
Cymatogaster aggregata				1		3		2		6
Cynoscion nobilis										1
Cyprinus carpio										
Damalichthys vacca										
Embiotoca jacksoni				3		7			1	1
Genyonemus lineatus	203			38	21	1	188	14	61	42
Girella nigricans						6				
Halichoeres semicinctus										
Heterostichus rostratus						2				
Hyperprosopon argrnteum				3			6			/2
Hypsopsetta guttulata										
Hypsurus caryi										
Lepomis macrochirus										
Leptocottus armatus										
Medialuna californiensis										
Menticirrhus undulatus	1									
Mustelus californicus										
Myliobatis californica										
Neoclinus blanchardi										
Oxyjulis californica										
Paralabrax clathratus						3	3	1	1	
Paralabrax maculatofasciatus	1						1			
Paralabrax nebulifer	1				3	1	7		4	1
Paralichthys californicus	2						1			
Peprilus simmilimus	10						2			3
Phanerodon furcatus						2			1	
Platichthys stellatas										
Rhacochilus toxotes										
Rhinobatos productus					1					1
Roncador sternsii				1						
Sarda chiliensia	31					3	28			33
Scomber japonicus	1									
Scorpaena guttata	1					1				1
Scorpaenichthys marmoratus					1	1	1			
Sebastes atrovirens	1									
Sebastes auriculatus										
Sebastes dallii							1			
Sebastes mystinus										
Sebastes rastrelliger	3									
Sebastes serranoides	21			1	1		4			526
Seriphus politus										1
Sphyraena argentea										
Squalus acanthias										
Synodus lucioceps										
Trachurus symmetricus										3
Triakis semifasciata										
Tridentiger trig.										
Xystreurys liolepis										

Table 15. October, 1978

Stations	1	2	3	4	5	6	7	8	9	10
Amphistichus argentus									1	1
Anisotremus davidsoni									3	2
Atherinops affinis	2						1			6
Atherinopsis calif	7	8			9		1	1		9
Cheilotrema saturnam						1			1	1
Cymatogaster aggregata	6	1			2		16	1		10
Cynoscion nobilis										
Cyprinus carpio										
Damalichthys vacca										
Embiotoca jacksoni					21	4	4		24	1
Genyonemus lineatus	43	7			17	12	23	52	29	68
Girella nigricans					1		4		22	
Halichoeres semicinctus										
Heterostichus rostratus									1	
Hyperprosopon argrnteum		2					5		1	
Hypsopsetta guttulata									1	
Hypsurus caryi										
Lepomis macrochirus										
Leptocottus armatus										
Medialuna californiensis							2			
Menticirrhus undulatus										1
Mustelus californicus										
Myliobatis californica										
Neoclinus blanchardi										
Oxyjulis californica						1				
Paralabrax clathratus	1					3			1	
Paralabrax maculatofasciatus										
Paralabrax nebulifer	4				1	1	7	1	3	4
Paralichthys californicus										
Peprilus simmilimus	79									2
Phanerodon furcatus							1		4	
Platichthys stellatas										
Rhacochilus toxotes										
Rhinobatos productus										
Roncador sternsii										
Sarda chiliensia	1						7			8
Scomber japonicus	1									5
Scorpaena guttata	1						2			1
Scorpaenichthys marmoratus										
Sebastes atrovirens										
Sebastes auriculatus										
Sebastes dallii										
Sebastes mystinus										
Sebastes rastrelliger										
Sebastes serranoides										
Seriphus politus	5				3		3	10	3	608
Sphyraena argentea										
Squalus acanthias										
Synodus lucioceps	2									
Trachurus symmetricus	2									12
Triakis semifasciata										
Tridentiger trig.										
Xystreurys liolepis										

Table 16. November, 1978

Stations	1	2	3	4	5	6	7	8	9	10
Amphistichus argentus										
Anisotremus davidsoni										
Atherinops affinis						1				2
Atherinopsis calif							2			8
Cheilotrema saturnam							1			6
Cymatogaster aggregata							1			
Cynoscion nobilis								4	2	
Cyprinus carpio										
Damalichthys vacca										
Embiotoca jacksoni									1	
Genyonemus lineatus						5	1		2	
Girella nigricans		8			14		7	25	36	28
Halichoeres semicinctus						1	12		4	
Heterostichus rostratus										
Hyperprosopon argrnteum						1				
Hypsopsetta guttulata								1		37
Hypsurus caryi										1
Lepomis macrochirus										
Leptocottus armatus										
Medialuna californiensis										
Menticirrhus undulatus										
Mustelus californicus										
Myliobatis californica										
Neoclinus blanchardi								1		
Oxyjulis californica										
Paralabrax clathratus										
Paralabrax maculatofasciatus						1	2		1	1
Paralabrax nebulifer										
Paralichthys californicus						2	1		2	4
Peprilus simmilimus										
Phanerodon furcatus										8
Platichthys stellatas						4		3	1	12
Rhacochilus toxotes										
Rhinobatos productus										
Roncador sternsii										
Sarda chiliensia	3									
Scomber japonicus	1					1	35			17
Scorpaena guttata										
Scorpaenichthys marmoratus										1
Sebastes atrovirens										
Sebastes auriculatus										
Sebastes dallii										
Sebastes mystinus										
Sebastes rastrelliger										
Sebastes serranoides									2	
Seriphus politus										
Sphyraena argentea										35
Squalus acanthias										
Synodus lucioceps										
Trachurus symmetricus	1						1			
Triakis semifasciata							1			2
Tridentiger trig.										
Xystreurys liolepis										

Table 17. Mean Abundance* of Fish by Block and Year (* in thousands, numbers rounded)

Year	Blocks 720	740	719	718	Total	Mean
1970	176	103	56	235	570	143
1971	134	156	95	168	553	138
1972	278	148	136	90	652	163
1973	269	184	170	65	688	172
1974	312	192	170	73	747	187
1975	358	211	135	65	769	192
1976	154	172	148	56	530	133
1977	168	132	294	29	623	156

Table 18. Anchovy Acoustical Trawl Survey Data, California Department of Fish and Game[1]

1973	2	million tons schooled
1974	1.8	million
1975	2.035^{o}	million
1976	1.1	million
1977	1.4	million
1978	0.530^{+}	million
1979	0.314*	million

o largest spawning biomass, poorest recruitment

+ late (April, May) good recruitment

* young 79 undersized due to late schooled fish but 6 kg/m^3 quite a bit less than last year

[1] published and unpublished data

MARINE-ASSOCIATED AVIFAUNA OF OUTER LOS ANGELES-LONG BEACH HARBORS IN 1978

INTRODUCTION

The marine-associated birds of the entire harbors area were studied on a weekly basis in 1973-74 (AHF, 1976) but no expert quantitative studies had been done until the present efforts in 1978. The 1978 studies addressed only the outer harbor and were of several sorts:

1) Expert quantitative surveys made on a quarterly basis by Dr. Dennis M. Power, Director of the Santa Barbara Museum of Natural History, with his colleague Paul Collins and HEP personnel.

2) Monthly surveys of common birds made in conjunction with the fish creel census.

3) Casual observations made on approximately a weekly basis during the course of other field work.

4) Weekday observations at one popular main channel shoreline fishing site.

Dr. Power's report on the quarterly survey is included in the following pages in its entirety because it is the only one of the four which can compare the 1973-74 data with the 1978 data.

The monthly survey information on common birds, observed at harbor locations where the creel census of shore anglers took place, follows Dr. Power's report. The daily and casual observations are on file with Harbors Environmental Projects, University of Southern California, as are all other raw data for these investigations.

In the 1973-74 investigations by Harbors Environmental Projects the harbor was surveyed almost weekly. The detailed report (AHF, 1976) presented computer analysis of data for a 14-month period from August 1973 through September 1974 in which 43 surveys were made. Site analysis and seasonality were included. Thus the baseline for comparison with the 1978 quarterly observations was unusually extensive.

A Quarterly Survey of Marine-associated Avifauna of the Outer Los Angeles and Long Beach Harbors in 1978 Compared with the 1973-74 Surveys

A survey of water and shore birds of the Los Angeles and Long Beach Harbors was undertaken in 1978 at the request of the Harbors Environmental Projects, Institute for Marine and Coastal Studies, Allan Hancock Foundation, University of Southern California, Los Angeles. The purpose of the study was to record the abundance and distribution of species of the marine-associated avifauna found in 1978 and to compare the results with a similar survey taken in 1973 and 1974 (August 10, 1973 through September 29, 1974). In addition, species richness at various stations throughout the harbor complex was measured in 1978 and the status of the endangered California Least Tern was assessed.

The results of this study bear on determining whether or not the harbor environment has been enriched by the Terminal Island sewer outfall boil. Secondary treatment of sewage was instituted in April 1977 and of cannery wastes in October 1977. It was of special interest to determine whether the marine-associated avifauna decreased between the 1978 survey and the 1973-74 survey, a time that secondary waste treatment was not in effect. Data for the 1973-74 survey were taken from the report entitled "Marine-associated Avifauna of the Los Angeles-Long Beach Harbors" (pp. 291-354) in AHF, 1976.

Scope

The survey embraced the outer Los Angeles Harbor, including the outer portion of the main channel, and outer Long Beach Harbor. Excluded were the inner harbor and U.S. Navy Facility area. The ornithological observation stations were those numbered X50 through X80 (Figure 1) already established by Harbors Environmental Projects.

All species of birds observed using the harbors in any way were included. The list of species in this report is composed totally of coastal and marine birds. A few non-marine species make use of the harbor, and these are listed on data sheets forwarded to Harbors Environmental Projects, but are not included in the analysis.

METHODS

The methods used for data acquisition relied simply on direct on-site identification and counting. There were two

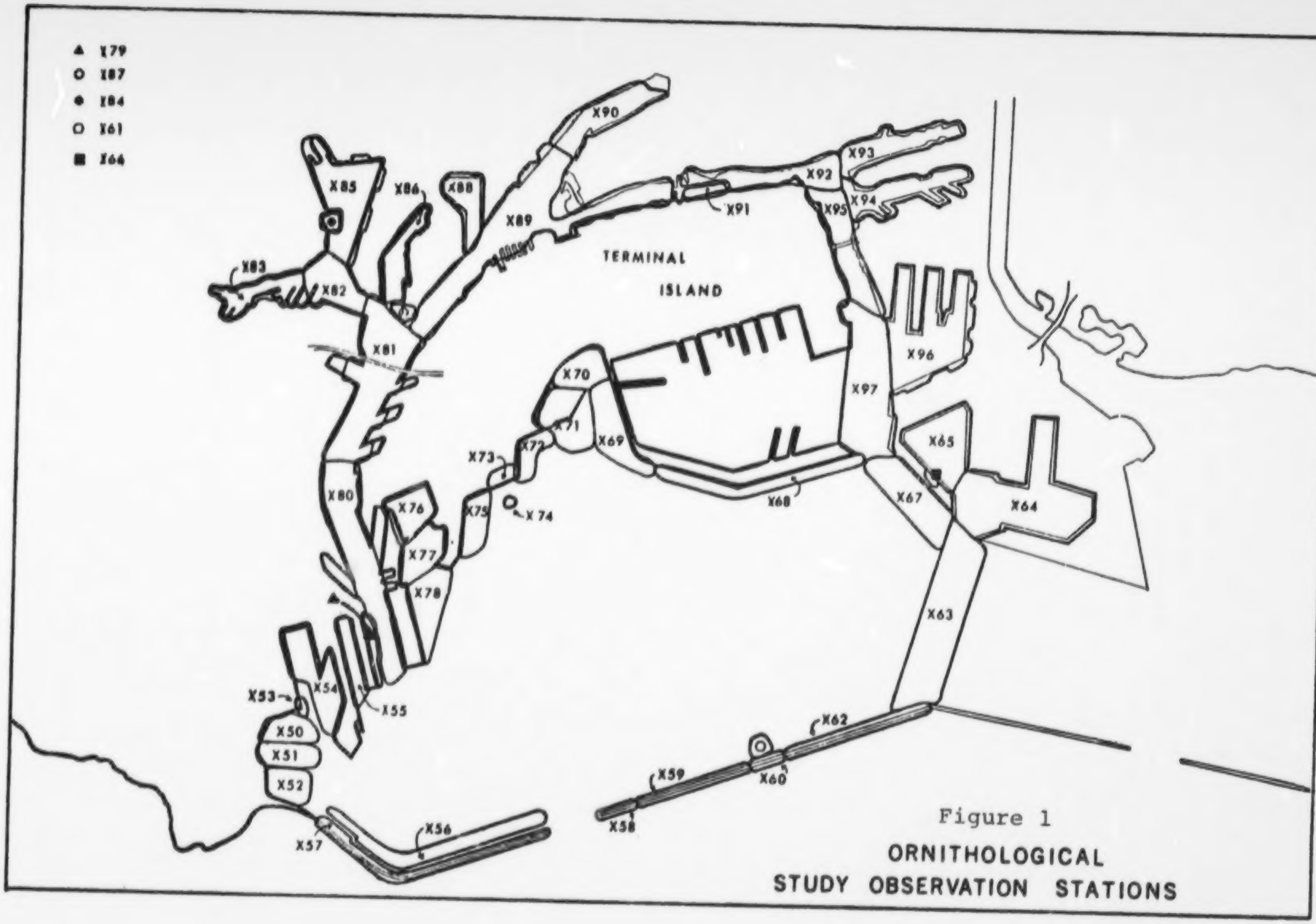

Figure 1
ORNITHOLOGICAL
STUDY OBSERVATION STATIONS

observers at all times -- the author, aided by Paul Collins, Associate Curator of Vertebrate Zoology at the Santa Barbara Museum of Natural History. A University of Southern California (USC) vessel was operated by USC personnel under the direction of the investigators. At set locations in the harbors, the birds present were counted and listed by species. Both investigators generally corroborated on identification and counts.

A description of each of the stations is included in AHF (1976) and will not be repeated here. The harbor was surveyed for one day in each season (quarter) in 1978 on the following dates: January 25, April 27, July 26, and October 25. These are all weekdays, and, with the exception of summer, are free of the influence of heavy recreational use of the harbor. Each survey started at 8:00 AM with observation on land of stations X73, X74, and X75, near the sewer outfall boil. At approximately 9:00 AM the observations from the water got underway aboard a USC boat. Observation began with station X80 and continued counter-clockwise in the harbors to take in, in order, X79, X55, X54, X53, X50, X51, X52, X57, X56, X58, X59, X60, X61, X62, and X63 (Cabrillo Beach and the breakwaters). Generally by noon the survey reached the vicinity of stations X64 through X67 (Long Beach), continuing in sequence through stations X68 through X80 (Terminal Island, the seaplane base, outfalls area, Fish Harbors and the Main Channel in Los Angeles). The survey usually ended at approximately 3:00 PM.

Observations were made with binoculars and, occasionally, with a 20-power spotting scope, at ranges of 5 to 50 meters. All birds were counted, even when in large groups; estimates of numbers were made only for groups that could not be counted, such as those in flight or in a flock that was startled partway through a count.

Weather was typical for each season in which a survey was made. On January 25 weather was recorded as "cool, clear, with light winds." On April 27 the weather was noted to be "moderate temperature, clear, with moderate wind." On July 26 the weather was "warm, calm, with a light haze." And, on October 25 the weather was "cool, clear, and with moderate wind." Abundance and distribution of species was therefore not affected by stormy or inclement weather.

Potential for Error

A number of potential error factors should be considered in determining the accuracy of this study. These are listed below.

Species identification. Errors in identification should be minimal. Both investigators are experienced field observers, and Collins has a particularly keen eye for rapid identification of shore and water birds. On the rare occasion that a species was not immediately identified with surety, checks were made with standard field guides that were carried during the survey.

Counting. This factor also appears to be subject to insignificant error. Often both observers made counts and compared results. In cases with larger numbers of birds (about 100 or more) one observer usually took one set of birds or one complex of species, while the other observer counted another set. For such large groups it is doubtful that the error rate exceeds five percent.

Location. The stations used in this survey were limited to water and land along the perimeter of the harbors and did not include the central areas of the outer harbors. This was to provide consistency between the 1978 survey and the 1973-74 survey. Investigators on the earlier survey concluded that the open water of the outer harbor was used principally by birds in transit. Furthermore, the area of the inner harbor (stations X81 through X97, Figure 1) were not included in the scope of the present survey. These location factors mean that the present survey underestimates the overall total number of individuals in the harbors on the day of the survey.

Time of day. According to the schedule given above, some stations were visited only in the morning hours, while others were seen only in the afternoon. We have no information, however, to suggest that particular species regularly frequented specific parts of the harbors only at certain times of day, or that their activity was restricted to certain sections according to the hour of the day. Variation in site use within the seven-hour period of the daily observation therefore does not seem to be a significant factor. One species -- the Black-crowned Night Heron -- may be more active at night.

Comparison with the 1973-74 study. Comparison between results of this study and the published results of the 1973-74 study cannot be made directly because of the different number of survey periods and observation stations. As already mentioned, the 1973-74 study took in the inner harbor, stations X81 through X97 (Figure 1), as well as the outer harbor. The 1978 study was only in the outer harbor. Furthermore, 14 observation periods were analyzed from among almost weekly surveys made in 1973-74, and only four were made in the present study. Ways to make the results comparable are discussed where appropriate in later sections of this report.

RESULTS

Species of Marine Birds and Overall Abundance

The numbers of water and shore birds recorded in the Los Angeles and Long Beach Harbors during the 1978 quarterly surveys are given in Table 1. Species are listed according to taxonomic family (e.g., loons, grebes), and both the common and currently accepted scientific names are given in each case. The total numbers recorded at all stations are given for each of the four surveys. The rankings in the right-hand column will be explained below.

Many species that breed outside of southern California, such as in the far north, spend the winter in the relatively mild climate here, or migrate through the area during spring and fall. In a highly disturbed site, such as the harbors, breeding activity and the number of nesting species is reduced. These two factors taken together lead to a decrease in bird species diversity in the harbors during the late spring and summer months. A slight depression in the number of species present is indicated in the 1978 survey results. The total number of water and shore bird species present at each of the four surveys in 1978 is as follows: 32 species in January, 30 in April, 28 in July, and 33 in October. During 1973-74, counts in comparable periods were : 45 in January, 30 in April, 21 in July, and 30 in October.

Much more dramatic is the seasonal change in absolute number of individual birds present (all marine species combined). Even for those species that are present during the normal breeding season, numbers may be reduced as the bulk of the population is on the nesting grounds outside the region. The total number of individuals, for each season, along with percent of the grand total for the whole year, are given in Table 2. The greatest number of individuals recorded -- nearly 40 percent -- was in the fall, the time of year during which many species are migrating from the breeding grounds to wintering areas, or have already arrived in the winter habitat. A relatively large population is present in the harbors during the winter. Lowest numbers are during spring migration and in the summer months. Actually, the spring survey was in late April, at which time many wintering species had already departed for breeding grounds elsewhere.

Most of the birds in the harbors are either roosting along breakwaters and piers, resting in protected waters, or feeding. The distribution of numbers indicates the importance of the harbor environment as a refuge and feeding area for marine birds during the fall and winter months, and for individuals of many species that, for one reason or another, are not with the bulk of the breeding population during the spring and summer months.

A comparison with the 1973-74 period shows roughly a similar seasonal distribution of numbers of individuals (Table 2). In these years there is an even greater proportion of the overall total that is found during fall and winter than in 1978, which may be due to the fact that the 1973-74 survey took in the inner harbor, an area frequented by large flocks of resting birds.

In order to determine if more birds were seen in 1978 than in 1973-74, or vice versa, we can compare the average numbers seen for each season. The average is obtained by dividing the number observed by the number of stations; there were 31 stations in 1978 and 48 stations in 1973-74. The results show (Table 2) that the average number observed in fall and winter was less in 1978 than in 1973-74.

It should be noted, however, that the method of averaging does not take into account certain important factors. First, by averaging by number of stations rather than area of stations, we are assuming that the average area of stations X50 through X80 is roughly the same as for stations X81 through X97. Areas are not the same, however; Figure 1 indicates that the sizes of stations in the inner harbor tend to be larger than those in the outer harbor. More birds could therefore be found in the greater area of the inner harbor stations and might bias the average number calculated. The bias would be that the 1973-74 survey would show more individuals per station. Second, large flocks of very numerous species, such as California, Heermann's, and Western Gulls, often prefer the quiet waters of the inner harbor for resting during the nonbreeding season. This also tends to bias the results in favor of larger average numbers in fall and winter of the 1973-74 survey, when the inner harbor stations were included.

To get a rough idea of whether or not the 1973-74 fall and winter surveys are unduly biased by including the inner harbor stations, we can look at the total numbers counted in 1978, in comparison with the 1973-74 results, for just stations X50 through X80. In the earlier report (AHF, 1976, Table 8.1), the bird species summed over time is given for each station. The total number of marine birds identified to species for stations X50 through X80 is 79,304. The 1976 Table 8.1 represents a total of 14 observation periods, and the average number of marine birds per period is therefore 5,665. The total number of marine birds in 1978 was 9,119, and the average number per observation period (four periods) is therefore 2,280. Thus, by comparing these averages, it does seem that there were clearly greater numbers of birds in the outer harbor in 1973-74 than in 1978.

This is a significant finding for it indicates that there were roughly 3,400 more birds in the outer harbor on the average survey day in 1973-74 than in 1978. This is about two and one-half times the number counted in 1978. That reduces down to an average of 109 more birds per station in 1973-74 than in 1978. Worded another way, the average number of birds per observation period in the outer harbor in 1978 is about 40 percent of what was seen in 1973-74. This, then, lends considerable credence to the results given above, which indicate greater numbers of fall and winter birds in the 1973-74 survey over the same periods in 1978.

The conclusion is that there were roughly two and one-half times more birds in the outer harbors in 1973-74 than in 1978 and that this difference is primarily for the fall and winter months. There were more species observed in 1973-74 than in 1978, but these numbers are influenced by the frequency of sampling.

A Comparison of Numbers of Each Species

The foregoing results show that there were fewer marine birds in the harbors during the 1978 survey than in 1973-74, and that this difference is greatest during the fall and winter. It now becomes of interest to see which species are contributing to the difference between the two survey periods. Table 3 shows the average number of each species of marine birds seen per survey over stations X50 through X80. The column of figures for the 1978 period was obtained by summing the results of observations for each species (Table 1) and dividing by four, the number of observation periods in 1978. Thus, the figures are as comparable as they can be, in that they represent counts for just the outer harbor and are the average numbers per survey.

According to the figures in Table 3, loons and grebes (families Gaviidae and Podicipedidae) have not decreased in numbers in recent years. In fact, the Red-throated Loon and Western Grebe appear decidedly more abundant in 1978 than in 1973-74. Records from the National Audubon Society (1976, 1977, 1978) annual Christmas counts were examined from the Los Angeles, Palos Verdes and Malibu area for 1974-77 in order to compare apparent trends in the area. These are indicated in Table 3 under Differences as A+ or A-.

The Brown Pelican (family Pelecanidae) and three species of cormorants (family Phalcrocoracidae) were also more abundant in 1978 than in 1973-74. The case of the Brown Pelican may be a result of the increase in nesting success this species has had after the population lows of the late 1960s and early 1970s. It is worthy of note that many pelicans were in the harbor in 1973-74 when they were very scarce along the coast; cannery wastes and anchovy may have helped support them during that period of stress.

The Great Blue Heron and Black-crowned Night Heron (family Ardeidae) were more abundant in 1978 than in 1973-74. No Snowy Egrets were seen in 1978, but one was seen in 1973-74.

The results for the ducks and geese (family Anatidae) were mixed. More Cinnamon Teal were recorded in 1978 than in 1973-74. Of greater significance is the Surf Scoter, one of the most abundant species in the harbors, which had decidedly lower numbers in 1978. The Surf Scoter was over three times more abundant on an average survey in 1973-74 than in 1978.

Among the shore-feeding species (families Charadriidae and Scolopacidae) there were generally fewer individuals in 1978 than in 1973-74. Of the 17 species, only four were more abundant in 1978; these being the Whimbrel, Spotted Sandpiper, Wandering Tattler, and Dunlin. The most common shore bird of both surveys was the Sanderling. However, it was more than eleven times more abundant in 1973-74 than in 1978. The Black-bellied Plover, Surfbird, Ruddy and Black Turnstones, Willet, and Western Sandpiper were common in the harbors in 1973-74, but their numbers were also decidedly lower in 1978.

The gull species (family Laridae, subfamily Larinae) were all lower in numbers in 1978 than in 1973-74. One of the most dramatic cases is the Western Gull, which averaged over 1,200 birds per survey in 1973-74, but dropped to only about 300 per survey in 1978. The California, Ring-billed, Mew, and Bonaparte's Gulls all showed decided decreases in 1978. In terms of proportion, the greatest change was seen in the California Gull; it was more than 23 times more abundant in 1973-74 than in 1978. In terms of absolute numbers, the greatest change was seen in the Heermann's Gull; there was an average of 985 more birds of this species per survey in 1973-74 than in 1978. Clearly the gulls showed the greatest decrease over the two survey periods. In contrast, only three gull species showed a distinct decline in the Audubon surveys along the coast.

Within the terns (family Laridae, subfamily Sterninae) the results were mixed. The endangered Least Tern was more abundant in 1978, and the Royal Tern, which had no records in 1973-74, was recorded with 66 individuals in October 1978. All of the other terns showed a decrease in 1978. In absolute numbers the most dramatic difference was seen for the common Forster's Tern, which was almost twice as abundant in 1973-74. The Least Tern will be discussed in more detail shortly.

The conclusion that can be drawn here is that not all species have decreased in numbers, and among those that have, the decrease is by no means uniform. The greatest decreases are found for some of the most common species, such as: Surf Scoter, Black-bellied Plover, Sanderling, Western Gull, Herring Gull, California Gull, Ring-billed Gull, Mew Gull, Bonaparte's Gull, Heermann's Gull, and Forster's Tern. A very few of the more common species, such as the Western Grebe and Brown Pelican, have increased their numbers in 1978 over that recorded in 1973-74.

Ranking of Species

In order to obtain an idea of the most abundant marine birds in the harbors, regardless of the time of year, species are ranked in order from the highest to lowest number of individuals recorded at the highest sighting for that species in 1978 (Table 4). For example, the most abundant species is the Heermann's Gull; 1, 564 individuals were seen in the fall. The second most abundant species is the Brown Pelican with 753 individuals encountered in the fall. The third most abundant species was the Western Gull, with 439 individuals seen in the spring, and the fourth most abundant is the Surf Scoter, with 324 individuals seen in the fall. This scheme is approximate in that it does not take into account the numbers of individuals seen at times of the year other than when the highest count was obtained. For example, the Western Gull is seen in relatively large numbers all year around, whereas the Brown Pelican occurred in relatively low numbers in winter and was only moderately abundant in spring and summer (Table 1).

A statistically reliable comparison cannot be made with the 1973-74 survey (AHF, 1976) because of the way the data are tabulated. The 1976 Table 8.1 recorded totals over time listed by station, and because surveys were only a month apart the same birds may be counted in several surveys. This was not at all as likely in 1978 because surveys were three months apart. Also, the 1976 Table 8.2 listed bird species by time with stations summed and thereby combined results for the inner and outer harbors. The 1978 survey was only of the outer harbor area. Nonetheless, some generalized comparisons can be made.

As in the 1978 survey, the Heermann's Gull was the most abundant species in 1973-74; 10,104 individuals were counted in September 1973. The Surf Scoter was second (4,915) in December 1973), the Western Gull third (4,411 in October 1973). In the 1978 survey considerably fewer California Gulls were recorded; this species ranked sixteenth in abundance in 1978. This is due to the fact that the inner harbor was not surveyed in 1978, and the main concentration of California Gulls in the 1973-74 survey was in the inner harbor, particularly Dominguez Slough.

If the 1978 species rankings are plotted on a log scale against abundance rank, a gradually decreasing curve is obtained (Figure 2). Abundance categories are arbitrarily designated on this curve and used in the following section to give a standard usage to the terms "abundant," "common," "scarce," and "rare."

Species Accounts by Avian Families

Loons. Common Loons are scarce in the harbors, and were recorded only in spring and summer in 1978. The Arctic Loon is slightly more common and also was found only in spring and summer. In 1973-74 these two species were recorded in small numbers in summer and winter. The Red-throated Loon is common and was encountered in winter and spring in 1978. In 1973-74 it was found sporadically throughout the year, but predominantly in the summer months. This variation suggests that the Red-throated Loon may be seen any time of year, but that it is variable from year to year. The Arctic and Red-throated Loons were more abundant in 1978 than in 1973-74.

Grebes. Western Grebes were abundant, being the sixth most common species encountered during the 1978 survey (Table 2). Members of this species occurred all year around, but peak numbers were in winter. This trend matched what was seen in the 1973-74 survey; however, in actual numbers, more were recorded in 1978 than in the earlier survey. In the species account for the Western Grebe in the earlier report there is the following statement (AHF, 1976, p. 296),

> "In the first year of observation, it occurred in flocks that at times numbered over 300. In the second winter, however, the numbers were drastically reduced with flocks seldom numbering more than 20. This is of particular importance, for throughout its range this species is decreasing."

The 1978 observation indicates that greater numbers of the Western Grebe are again using the Los Angeles-Long Beach Harbors.

Eared Grebes were common in fall and winter both in the 1978 and the 1973-74 surveys. Horned Grebes were scarce in the 1978 survey and were confined to fall and winter. The Pied-billed Grebe was said to be rare in the harbor in the 1973-74 survey; it was not recorded in the 1978 survey, confirming its rarity in the harbors.

Pelicans. The Brown Pelican was abundant and is seen all year around, but in decidedly lower numbers in winter. As a result of a fall peak in numbers it was considered the second most common bird during the 1978 survey. It occurred in great concentrations along rocky breakwaters. Roughly 100 more of this species per survey were recorded in 1978 than in 1973-74, perhaps reflecting the greater breeding success the Brown Pelican has had over that in the late 1960s and early 1970s. DDT levels around White Point outfall and elsewhere were proposed as the reason for breeding failure or mortality (Young, McDermott and Heezen, 1976). DDT levels were several orders of magnitude lower in harbor sediments in 1974 than at Whites Point (Chen and Lu, 1974), which may have helped the population.

Cormorants. The Double-crested Cormorant was common the year around, with peak numbers occurring in winter and spring.

This species was also relatively abundant in the winter of 1973. A marked decline in 1974 seemed to be only a temporary decrease, as the species ranked as the tenth most common bird during the 1978 survey. Brandt's and Pelagic Cormorants were scarce, but also may be seen all year.

Herons. The Great Blue Heron was common and was seen in summer and fall, but with greatest numbers in the winter. None were seen in the spring survey of 1978. This pattern of seasonal variation in abundance was similar to that found in the 1973-74 survey.

One Black-crowned Night Heron was seen from time to time in the 1973-74 survey. However, it was predicted that the species may be more common than indicated by these single sightings because of the species' nocturnal habits. This was confirmed in 1978 when 13 were counted in July.

The Green Heron and Snowy Egret were seen sporadically in 1973-74, but were not recorded in 1978.

Ducks and Geese. The Surf Scoter was abundant in the harbor during 1978, ranking fifth in number of individuals at the highest sighting. It was the most common species of duck in both the 1978 and 1973-74 surveys; however, absolute numbers are down considerably in 1978. Lesser Scaup and Cinnamon Teal were common during the winter of 1978, an observation that also agrees with the 1973-74 survey.

Pintail were scarce; a few may be encountered in winter. One Common Scoter was observed in April 1978. This species was also rare in the 1973-74 survey, but was seen at times of the year other than spring. One White-winged Scoter was seen in July 1978. A few of this species were recorded throughout the year in 1973-74.

Red-breasted Mergansers were seen in January and April in 1978, and are considered scarce. This matches the seasonal occurrence and relative abundance for 1973-74 as well.

One Canvasback was seen in January 1978; this species was not recorded in 1973-74. Ruddy Ducks and Common Mergansers were rare in the 1973-74 observation period, but were not observed at all in 1978. Black Brant were slightly more abundant in 1973-74, but also were not encountered at all in 1978.

Rails. Two American Coots were seen in October 1978. In 1973-74 this species was regarded as infrequent in the harbors, with only rare sightings in September and December.

Oystercatchers. Two Black Oystercatchers were recorded in April 1978, which corresponds to sighting of a very few in spring surveys in 1973-74.

Plovers and Allies. The Black-bellied Plover and Ruddy Turnstone were common and the Black Turnstone scarce in the harbors all year around in 1978. Relatively greater numbers were seen in fall and winter months for the Black-bellied Plover. For the Ruddy Turnstone, highest counts were in April; the Black Turnstone was seen in low but consistent numbers (5-9) throughout the year. In 1973-74 the peak abundance was in August and March for the Ruddy Turnstone, and in April for the Black Turnstone; fewer of these species were recorded in 1978 than in 1973-74.

In the 1973-74 survey, Killdeer were seen regularly; however, in the 1978 survey only five were recorded, and these in October. This species is considered scarce. The Snowy Plover is rare; one bird was seen in April 1978. Snowy Plovers were also rare in the 1973-74 survey, but were observed in August and November, rather than spring. During other intertidal surveys in 1976-78, Snowy Plovers were seen frequently on outer Cabrillo Beach, outside the breakwater, and occasionally inside at X51 and X52. In 1978 the Surfbird was scarce; a few were seen in the spring, summer and fall surveys. In 1973-74 migratory concentrations of higher numbers of Surfbirds were observed in March and April.

The Semi-palmated Plover -- observed infrequently in the 1973-74 survey -- was not encountered in 1978.

Sandpipers. The Whimbrel was scarce in 1978 -- a small number was counted in both April and July. In 1973-74 a few were also recorded in winter and spring. Spotted Sandpipers were also scarce; however, they were recorded in all four surveys in 1978. In 1973-74 a few Spotted Sandpipers were recorded in all months except May, June and July. Wandering Tattlers were seen in fair numbers in April and July 1978, and three were observed in October; they are therefore considered common. In 1973-74 the Wandering Tattler was considered primarily a winter resident, leaving the harbor by late April. These three species were all somewhat more numerous in 1978 than in 1973-74.

The Willet, unlike most other species, did not have a similar abundance pattern in the two observation periods. In 1978, 20 to 27 were found in summer, fall and winter -- none were recorded in spring. In the 1973-74 survey, on the other hand, peak numbers occurred in March and April. In absolute numbers it was also more abundant in 1973-74.

The Least Sandpiper was recorded in low numbers in January and October in 1978; it is considered scarce. In 1973-74 it was also recorded in spring, with one or two migratory peaks in August. The Dunlin was recorded only in

October 1978, and is considered scarce. In 1973-74 this species was also recorded in the spring.

Two Western Sandpipers were recorded in October 1978. However, in 1973-74, the species occurred in large numbers and was seen primarily in spring. Western Sandpipers may therefore briefly migrate through the harbors and were simply not encountered in 1978. One Marbled Godwit was seen in 1973-74 and in many other months. The Sanderling was seen in greatest numbers in January and April 1978 and is considered common. Peak abundance also occurred in winter and spring in the 1973-74 survey; however, in general it was much more abundant than in 1978.

Gulls and Terns. As a group, gulls are exceptionally abundant in the harbors. The Heermann's Gull was found throughout the year and ranked as the most common species. Heermann's Gulls are especially numerous in summer and fall, with 754 and 1,564 being recorded in July and October 1978, respectively. In winter and spring they are also abundant. In the 1973-74 survey, Heermann's Gull was regarded as the most numerous bird in the harbors, occurring in very great numbers in September and October. In overall numbers, however, it has decreased decidedly (by 46 percent) in 1978.

The Western Gull is the most consistently abundant species and ranks third in greatest numbers at the highest sighting. Numbers ranged from 250 to 439 per day in 1978. This same pattern was also noted in the 1973-74 survey, during which it was regarded as the second most abundant species in the harbors. This species was found in significantly fewer numbers in 1978 (only about 14% of 1973-74 average).

Glaucous-winged Gulls -- considered scarce in the present study -- were seen in January 1978, and from late October to early June in 1973-74, with peak numbers in December. Herring Gulls -- considered common in the present study -- were also largely restricted to the winter observation period in 1978. However, in 1973-74 they were seen at other seasons, and in greater numbers. Moderate numbers of California Gulls were seen in April and October in 1978; they are considered common. California Gulls were abundant in winter months in 1973-74, but were primarily in the inner harbor, an area not covered in the 1978 survey. Outside the inner harbor, however, they were much more numerous in 1973-74 than in 1978. In 1978 the Ring-billed Gull was abundant and seen in peak numbers in winter, with smaller numbers in spring and fall. In 1973-74 it was also common and also had peak numbers in the winter months. It, too, was much more numerous in 1973-74.

One large flock of Mew Gulls was recorded in January 1978; the species was sparse or absent at other times of the year. In 1973-74 a winter peak was also recorded for the Mew Gull.

Bonaparte's Gull was abundant, being commonly seen at all seasons except summer in the survey of 1978. In 1973-74 this species was also absent in summer, with peak numbers occurring in winter. Bonaparte's Gulls were more numerous in 1973-74 than in 1978. The Black-legged Kittiwake was common in 1978, being recorded in moderate numbers in January and April. In 1973-74 the winter and spring were also peak seasons for this species, and about 3 times as many individuals were seen as in 1978.

Among the terns, Forster's Tern was abundant, occurring in greatest numbers in spring and fall. Spring, late summer, and fall were also peak times for this species in 1973-74, with at least some birds being seen the year around. In these years Forster's Terns were more abundant than in 1978. For the Least Tern, 35 were seen in April and only two in July 1978. In 1973-74 Least Terns were also recorded in spring and summer. More will be said about this species in a separate section. Elegant Terns were common, being recorded in moderate numbers in July and October 1978. This matches the period it was present in 1973-74. One Caspian Tern was recorded in July 1978, and a few were recorded in most seasons of the 1973-74 survey.

Sixty-six Royal Terns were recorded in October of 1978, giving this species a rating as common. However, this species was not seen in 1973-74. On the other hand, a few Common Terns were seen in the 1973-74 survey, but were not recorded in 1978.

Kingfishers. The Belted Kingfisher is considered scarce. One bird was recorded in July, and four in October of 1978. In 1973-74 it was recorded in fall, winter and spring, being absent most of the summer.

Species Richness at Harbor Stations

The various stations or observation sites throughout the harbors (Figure 1) have different physical attributes, such as sandy beach, rocky breakwaters, sheltered coves, partially submerged structures, and intact and decaying wooden piers, just to name a few of the variables. In addition, microclimate and biotic properties of the water vary from site to site. Generally, those sites with the greatest physical heterogeneity tend to support a greater diversity of bird species than do very uniform sites. The numbers of species of water and shore birds (generally termed "species richness") is roughly correlated with habitat complexity, and, because one of the goals of conservation is to maintain ecological diversity, the more physically diverse sites are usually the most desirable ones to maintain. Sheltered areas, protected from rough seas and prevailing winds, are equally desirable for roosting areas. In addition, the food chain may be artificially enhanced by sewage outfall or effluent from canneries, which adds yet another component to the ecological complexity of a site.

In Table 5 the species richness at each station is given for each of the four seasonal surveys in 1978. In addition, the total number of individual water and shore birds is also given for each station. Size and position of a station within the harbor may be determined by comparing Table 5 with the map in Figure 1.

Seasonal differences in average species richness are immediately apparent. The average number of species per site was greatest in winter (8.38/station) and during spring migration (7.23/station). Lowest average species richness was in the summer (3.6/station) when many of the species are on breeding grounds to the north. The greatest average number of individuals was in fall migration (114.97/station), while the lowest were in spring migration (52.13/station) and summer (55.97/station).

Two stations -- X71 and X75 -- have relatively high species richness and a large number of individuals at all times of the year. Station X71 contains a protected embayment, a rock pier, a portion of open water in the outer harbor, and partially submerged structures. This physical diversity seemingly provides a protected environment and relatively rich source of feeding zones, which is in turn reflected in a relatively rich marine avifauna. An average of 16 species was seen per survey at X71. Shorebirds forage along the rocks, and gulls and terns feed in the adjacent water. The protected water provides a resting area for ducks, grebes and loons, and the rock pier is a roosting site for large numbers of gulls, terns, cormorants and pelicans. In addition, the site is relatively free from human disturbance.

Station X75 is also physically diverse, containing rock wall at water's edge, sand beach exposed at low tide, open water, and a partially submerged wooden boat on which shorebirds may feed, and gulls, pelicans and cormorants are often seen to roost. An average of 16 species per survey was also seen at X75. This station included the two cannery waste outfalls in 1973-74; these were discontinued at the end of 1977.

Another station with relatively high species richness (an average of 12 species/survey) is X62. This site is the rocky outer breakwater, which, as a roosting site, attracts gulls, pelicans and cormorants. It is also used as a feeding area by a variety of shorebirds. In the 1973-74 survey, stations X71 and X62 were also identified as species-rich sites.

The impact of human disturbance is evident when the seasonal differences at stations X50, X51 and X52 are compared. These sites are relatively protected from wind and contain piers, rocky shore and sand beach, and open water. During the surveys in January, April and October there was very little public use of these stations, and average species richness for all three stations was 9.33 species/station in January, 7.67 in April, and 8.00 in October. However, in July, station X51 was in heavy use by swimmers, boaters, and surf-skiers. At this time average species richness for the three sites fell to only 0.67 species/station. Specifically, at the July survey only two species totalling eight individuals were recorded at X50 and no species were seen at all at X51 and X52. These findings support the belief that high species richness in areas such as X71, X75, and X62 are in part due to an absence of human disturbance.

Site-to-site trends and seasonal variation in species richness and numbers of individuals are evident in Table 5 and need not be discussed in detail here. Instead, it is worthwhile to examine more closely the results of surveys at the sewer outfall boil, station X74.

Marine Birds Near the Sewer Outfall (Stations X74 and X75)

Station X74. The species of water and shore birds recorded at the sewer outfall boil, station X74, in 1978 are listed in Table 6. Most of the birds at the sewer boil were resting individually or in flocks on the water in the vicinity of the outfall boil. On January 25, 1978 one Western Grebe was seen actually at the effluent plume, and a small group of eight Surf Scoters was nearby. On April 27, 1978 no birds were actually at the boil, but nearby were Brown Pelican, Surf Scoter, Double-crested Cormorant, Western Grebe, Western Gull, and Forster's Tern. On July 26, 1978 again no species were actually at the plume; however, the following species were resting or feeding elsewhere at the station: Brown Pelican, Common Loon, Least Tern, Elegant Tern, Surf Scoter, Brandt's Cormorant, and Heermann's Gull. One Brown Pelican was observed sitting at the plume, but only briefly. Two Least Terns were in the immediate vicinity for awhile, and one dove to feed there on a single occasion. This was during the period when the TITP upset occurred and particulates were released in the effluent.

On October 25, 1978 there was again no bird activity directly at the boil. A large flock of Surf Scoters was in the vicinity and four Eared Grebes and four Forster's Terns were elsewhere at the station.

In general, in 1978 there is no greater number of species or individual birds at the sewer outfall boil itself than would be expected at a similar station elsewhere in the harbors.

There is certainly no evidence of enhancement of the immediate site in 1978 due to the effluent plume, especially since there is no resting area involved and habitat diversity is low.

To determine if the sewer outfall actually enhanced bird species diversity at the site before secondary water treatment was begun, a comparison can be made between the results of the 1978 survey, with secondary waste treatment, and the results of the 1973-74 survey, when no secondary waste treatment was in effect. In the earlier report, bird species were summed over the 14 monthly surveys during 1973-74 and listed for each station (AHF, 1976, Table 8.1). The following species were recorded for station X74 during 1973-74: Least Sandpiper (2), Caspian Tern (1), Heermann's Gull (37), Western Gull (1), Bonaparte's Gull (511), Brown Pelican (15), Double-crested Cormorant (2), and Forster's Tern (44).

The high incidence of Bonaparte's Gulls in 1973-74 indicates that this species was probably using the sewer outfall zone for feeding. In fact, the earlier report states (AHF, 1976, p. 304), "From February to March this species is seldom seen anywhere but the sewer outfall . . ." The earlier report also indicated that there was a large number of dates on which no birds were present at the boil, suggesting that this station was not at all times a preferred habitat. Furthermore, Heermann's Gulls, Forster's Terns and Bonaparte's Gulls occurred at the sewer outfall only during their population peaks in the harbors, which suggests that this station may be used only when population pressure forces feeding in less than optimum areas. The fact that these three species were present in 1978, but in low numbers and were not feeding, suggests that secondary waste treatment plus elimination of cannery waste has removed some direct source of food for at least those species mentioned.

The earlier report (p. 351) also stated that Bonaparte's Gulls and Forster's Terns would suffer from the elimination of the outfalls. The present survey indicates that with secondary waste treatment at station X74, these species still exist in the harbors and have presumably found similar or suitable resources at other sites, but their numbers are greatly reduced in the harbors overall (Table 3).

In conclusion, the sewer outfall at station X74 provided a specific feeding area for Bonaparte's Gulls, Heermann's Gulls, and Forster's Terns before secondary waste treatment was in effect. However, for these species, and others that may occur there from time to time, the station itself seems to be a secondary feeding site that is utilized probably only during population peaks.

Station X74 and X75. A more meaningful comparison can be made by treating stations X74 and X75 as combined. Station

X75 is a rocky jetty, formerly with a sandy cove, where the cannery waste discharge pipes were located and adjacent to the sewer boil, station X74. Table 7 gives, for both the 1973-74 and 1978 surveys, the total numbers of birds at both stations summed for all observation periods. In addition, the average number per observation period is given (total divided by 14 for 1973-74 and total divided by 4 for 1978). It is first of all obvious that there was an increase in number of species in 1978 at these two sites: 34 species in 1978 as compared to 28 in 1973-74. There is, however, a decrease in total numbers of individual birds, even when the very large count for the Sanderling is omitted. It is interesting to speculate that there may be a causal relationship between the decrease in number of individuals and the increase in number of species in 1978.

As indicated in the table, loons and grebes showed an increase at stations X74 and X75 in 1978. The Brown Pelican and three species of cormorants are also up in numbers. Likewise, among the ducks (teal, scaup, Canvasback and scoter) the numbers are greater in 1978. This is particularly interesting for the Surf Scoter, since it has been shown elsewhere in this report that this species has decreased overall in the harbors in 1978. This suggests that the area may be comparatively richer than surrounding areas, with the reduction in total wastes disseminated.

The plover and sandpiper groups show mixed results. The Surfbird, Ruddy Turnstone, Black Turnstone, Whimbrel, Spotted Sandpiper, and Wandering Tattler appear in greater numbers in 1978. The Least Sandpiper, Dunlin, Western Sandpiper, Sanderling, Marbled Godwit, and Long-billed Dowitcher were in greater numbers in 1973-74. The Sanderling is especially worth noting for it was considerably more common in the earlier survey; in fact, on one day alone (December 29, 1973) 500 were seen at X75.

For the gulls there is quite a different story. For nine out of ten gull species, there were fewer numbers in 1978 than in 1973-74. The difference is most noticeable for the Western, California, Ring-billed, Bonaparte's and Heermann's Gulls. For the terns, fewer Forster's and Caspian Terns, but greater numbers of Least and Elegant Terns were seen in 1978.

In conclusion, taken together, stations X74 and X75 remain important sites for marine birds in 1978. There is a variety of feeding and roosting substrates, and the sites are relatively free from human disturbance. There has been, however, a clear decrease in the numbers of most gull species in 1978, as compared to the situation in 1973-74. This may reflect the reduction in particulate matter in the effluent and in fish attracted to the area.

The California Least Tern on Terminal Island

Early in this century the Least Tern (*Sterna albifrons*) was an abundant breeding bird in California. Land development and recreational use of the coast reduced the population of the California race (*browni*) to such low numbers that its continued survival was in doubt. In 1970 the California Least Tern was declared "endangered" by federal law, and in 1971 the State of California followed suit.

The Least Tern arrives each spring on the west coast of California and Baja California, presumably from wintering grounds in South and Central America. Breeding colonies are established on beaches and sand flats from Moss Landing, Monterey County, to southern Baja California. Preferred habitat for nesting is uninhabited beach adjacent to estuaries with a good supply of small fish.

In recent years, the California Department of Fish and Game has sponsored Least Tern census and nesting surveys. Included in this body of work are surveys of the nesting success on Terminal Island. In 1974, ten pairs were seen in May at station X73 and had progressed to the courtship feeding stage. Landfill and grading operations on the site, however, disrupted the colony and no successful breeding was recorded. The same thing reportedly occurred in the 1973 breeding season as well.

In 1975, 24 pairs established some 40 nests at station X73. The site remained relatively undisturbed during that year and at least 35 young were fledged from this one colony. In 1976, station X73 was covered in a relatively heavy growth of weeds and nesting there was thwarted. However, some 60 pairs established a breeding colony about one-half mile northeast on Reeves Field, an abandoned airstrip beyond stations X70 and X71. The airstrip is mostly old asphalt covered with patches of sand and weeds, and is used in some years for the storage of imported automobiles. Nesting success here was very good, and some 60 pairs eventually fledged about 50 young. In 1976 it was learned that there had been some successful nesting at the site by the California Least Tern in 1973 and 1974 as well.

In 1975 station X73 still had a relatively heavy growth cover, but a colony of some 85 pairs was reestablished at Reeves Field. Approximately 80 young were fledged. In 1978 station X73 was graded and attempts were made to minimize public access; however, there was no nesting. Instead, nesting was initiated again at Reeves Field, but in this year grading and fencing of the site during the pair-formation stage disrupted the colony. Pairs apparently dispersed to colonies at nearby San Gabriel River, Huntington Beach and possibly other sites holding other breeding colonies. The success of these displaced birds is not certain. It is clear that station X73, and especially Reeves Field behind stations X70 and X71, are suitable nesting sites for the California Least Tern. Mitigating measures should be undertaken to prevent disturbance during the nesting season, prevent destruction of the sites, and to enhance the area as a breeding grounds for this endangered subspecies.

There seems to be no significant change in numbers of California Least Terns in 1978 over what was found in 1973-74.

SUMMARY

This study is to assess the distribution and abundance of marine species in the Los Angeles-Long Beach Harbors during four quarterly surveys in 1978. A comparison was made with the results of a similar study conducted in 1973 and 1974. The results are intended to bear on determining changes in the harbor environment following the implementation of secondary waste treatment of the Terminal Island sewer outfall.

Overall, the greatest numbers of species and individual marine birds occurred in the fall and winter (the nonbreeding season). However, a comparison of numbers between the present (1978) and the 1973-74 surveys shows that there were roughly two and one-half times more birds in the outer harbors in 1973-74 than in 1978. The differences were primarily in the fall and winter months; there seem to be no major differences during spring and summer. The greatest decreases were found for the most common species, such as Surf Scoter, Black-bellied Plover, Sanderling, Western Gull, Herring Gull, California Gull, Ring-billed Gull, Mew Gull, Bonaparte's Gull, Heermann's Gull, and Forster's Tern. Not all species decreased; a few of the more common species, such as the Western Grebe and the endangered Brown Pelican, showed an increase in 1978.

Species were ranked by abundance in 1978, and species accounts by families are given. The composition of the avifauna in the harbors was not greatly different in 1978 from 1973-74; in other words, with a few exceptions the same species were present in both periods. Species richness at harbor stations was also assessed. The highest average number of species per station was 8.38 in winter, and the low was 3.6 per station in summer in 1978. The greatest average number of individuals was 114.97 per station in the fall, while the lowest was 52.13 per station in spring. Stations that have relatively high physical diversity and are undisturbed by humans have highest species richness and a large number of individuals throughout the year (e.g., stations X71, X75, and X62).

In 1973-74, the sewer outfall boil at station X74 appeared to be a specific feeding site, but a secondary one, for

Bonaparte's Gulls, Heermann's Gulls and Forster's Terns. In 1978 the sewer outfall boil was not a feeding site of any importance for any species.

A review of census and nesting surveys of the endangered California Least Tern indicates that the species has in various years established breeding colonies in the harbors at station X73 and at Reeves Field, near stations X70 and X71. There had been good nesting success in recent years when the sites remain undisturbed.

CONCLUDING REMARKS ON THE HARBOR SURVEY

The data presented here are consistent with the concept that secondary waste treatment of the effluents in the Los Angeles-Long Beach Harbors has removed a source of enrichment of the harbor food chain that was present before secondary waste treatment was in effect. The sewer outfall boil itself seems never to have been a highly preferred, primary feeding site for any species of marine birds, probably because it is entirely turbulent water. The cannery effluent site was preferred and still is. The condition of nonsecondary-treated effluent in 1973-74 and earlier years, however, may have had an enriching effect on the food chain, which accounted for higher numbers of Surf Scoters, Black-bellied Plovers, Sanderlings, Forster's Terns, several species of gulls, and possibly other species as well, during the fall and winter months (nonbreeding season). The data do not prove this hypothesis because the direct links in the food chain are not identified and natural cycles of abundance of food organisms are not known. Furthermore, whether a sewage-enhanced environment is desirable or "natural" is a subjective case which is beyond the scope of the present work. However, certain native marine species were present in considerably greater numbers in 1973-74 than in 1978.

MONTHLY SURVEYS OF COMMON BIRDS

In conjunction with the creel census of shore anglers and catches, observations were also recorded on the common birds in the immediate area of 8 locations surveyed (Figure 3), by Donna Cooksey and Michele Smith. The following notes were made by them on the species groups they listed in Table 8.

Gulls - Gulls were abundant all through the year and at all locations. The most common gull was Heermann's Gull, especially during the summer months. Western Gulls and California Gulls were also seen in large numbers; however, Ring-billed Gulls were seen only in the fall observations. The largest numbers of gulls were seen at the Navy Mole in November resting on the water.

Terns - Very few terns were seen during the spring and summer observation periods, the majority occurring in the fall (October-November). The most commonly identified tern was Forster's Tern.

Pelicans - Pelicans appeared in the largest numbers beginning mid- to late summer and remained abundant through the fall months. Large numbers of juveniles were seen in October.

Cormorants - Cormorants were abundant mostly in the spring and occurred mainly around the barges on the inside of the Navy Mole. The numbers of cormorants peaked in March, with the Doublecrested Cormorant outnumbering the Brandt's Cormorant by a large margin.

Others - The others category usually consisted of Surf Scoters resting on the water for all areas. In late fall, however, they were joined by White-winged Scoters in increasing numbers at Belmont Beach Pier. Also included in this category but to a lesser degree were Western Grebes, Horned Grebes, Arctic Loons, and Common Loons.

OTHER OBSERVATIONS OF BIRDS IN OUTER LOS ANGELES HARBOR

From December 1977 to September 1978, birds were counted by three observers in limited areas of Los Angeles Harbor. At the end of the Municipal Fish Market Pier on Terminal Island (Figure 3, site 2) John Batey of the City of Los Angeles Bureau of Engineering counted grebes and pelicans. He made counts during the noon hour on 5 to 16 days per month through January 1979.

Birds were counted by Dr. Mary Wicksten during 5-minute watches once a month at stations X52, along the beach by the Sea Scout Base at Cabrillo Beach, San Pedro, and X57, along the inner side of the San Pedro Breakwater across from the fishing pier parking lot at Cabrillo Beach (Figure 1). Birds were recorded as resting, flying, or feeding.

Additional observations were made near Fish Harbor, the Terminal Island Treatment Plant outfall, and the main shipping channel by David Schomisch during other HEP field surveys. Birds were watched from the boat *Bugula* 1 to 3 times per month during 5-minute periods. Data were taken at these stations for all months except December 1977 and June 1978. The same activities of the birds were recorded at these stations as was done at Cabrillo Beach.

For ease of comparison, average counts per species per day of observation were tallied for stations that were counted more than once per month. Unidentified pelicans are included in the counts for Brown Pelicans. Unidentified terns are included in the counts of Forster's terns. Any unidentified grebes are considered to be Eared Grebes.

No significant differences were noted between the areas observed except for counts of shore birds. These birds, requiring a sandy beach, were largely confined to station X52. Gulls were the must abundant birds in all areas. Brown Pelicans, an endangered species, could be seen at all areas. Eared Grebes, Western Grebes, and Surf Scoters decline in summer when they migrate out of the Los Angeles area.

LITERATURE CITED: See Section VI.

Table 1. Numbers of water and shore birds recorded in Los Angeles-Long Beach Harbors during quarterly surveys in 1978.

Species	January	April	July	October	Rank[1]
Loons (Gaviidae)					
Common Loon (*Gavia immer*)	--	5	3	--	36.5
Arctic Loon (*Gavia arctica*)	--	21	2	--	26
Red-throated Loon (*Gavia stellata*)	28	30	--	--	20
Grebes (Podicipedidae)					
Horned Grebe (*Podiceps auritus*)	3	--	--	2	43
Eared Grebe (*Podiceps nigricollis*)	55	2	--	20	13
Western Grebe (*Aechmophorus occidentalis*)	225	109	27	40	6
Pelicans (Pelecanidae)					
Brown Pelican (*Pelecanus occidentalis*)	20	229	253	753	2
Cormorants (Phalacrocoracidae)					
Double-crested Cormorant (*Phalacrocorax auritus*)	72	73	20	42	10
Brandt's Cormorant (*Phalacrocorax penicillatus*)	1	2	6	1	33
Pelagic Cormorant (*Phalacrocorax pelagicus*)	5	5	--	3	36.5
Herons (Ardeidae)					
Great Blue Heron (*Ardea herodias*)	19	--	5	4	27
Black-crowned Night Heron (*Nycticorax nycticorax*)	--	--	13	--	28
Ducks and Geese (Anatidae)					
Pintail (*Anas acuta*)	4	--	--	--	40.5
Cinnamon Teal (*Anas cyanoptera*)	65	--	--	--	12
Lesser Scaup (*Aythya affinis*)	29	--	--	--	21
Canvasback (*Aythya valisineria*)	1	--	--	--	50

Table 1 (Cont.)

Species	January	April	July	October	Rank[1]
Surf Scoter (Melanitta perspicillata)	308	174	225	324	4
Common Scoter (Melanitta nigra)	--	1	--	--	49.5
White-winged Scoter (Melanitta deglandi)	--	--	1	--	49.5
Red-breasted Merganser (Mergus serrator)	6	2	--	--	33
Rails (Rallidae)					
American Coot (Fulica americana)	--	--	--	2	45
Oystercatchers (Haematopodidae)					
Black Oystercatcher (Haematopus bachmani	--	2	--	--	45
Plovers, Turnstones and Surfbirds (Charadriidae)					
Killdeer (Charadrius vociferus)	--	--	--	5	36.5
Snowy Plover (Charadrius alexandrinus)	--	1	--	--	49.5
Black-bellied Plover (Pluvialis squatarola)	44	9	8	28	17
Surfbird (Aphriza virgata)	--	4	3	3	40.5
Ruddy Turnstone (Arenaria interpres)	5	23	5	17	25
Black Turnstone (Arenaria melanocephala)	9	5	9	6	30.5
Sandpipers (Scolopacidae)					
Whimbrel (Numenius phaeopus)	--	6	2	--	33
Spotted Sandpiper (Actitis macularia)	3	9	7	4	30.5
Wandering Tattler (Heteroscelus incanus)	--	16	24	3	24
Willet (Catoptrophorus semipalmatus)	20	--	21	27	22.5
Least Sandpiper (Calidris minutilla)	5	--	--	4	36.5

Table 1 (Cont.)

Species	January	April	July	October	Rank[1]
Dunlin (*Calidris alpina*)	--	--	--	4	40.5
Western Sandpiper (*Calidris mauri*)	--	--	--	2	45
Sanderling (*Calidris alba*)	52	30	--	9	14.5
Marbled Godwit (*Limosa fedoa*)	1	--	1	--	49.5
Gulls and Terns (Laridae)					
Glaucous-winged Gull (*Larus glaucescens*)	10	--	--	--	29
Western Gull (*Larus occidentalis*)	250	439	264	290	3
Herring Gull (*Larus argentatus*)	52	--	--	1	14.5
California Gull (*Larus californicus*)	--	45	--	18	16
Ring-billed Gull (*Larus delawarensis*)	183	42	1	68	7
Mew Gull (*Larus canus*)	292	--	--	1	5
Bonaparte's Gull (*Larus philadelphia*)	134	68	--	54	9
Heermann's Gull (*Larus heermanni*)	175	44	754	1,564	1
Black-legged Kittiwake (*Rissa tridactyla*	12	27	1	--	22.5
Forster's Tern (*Sterna forsteri*)	45	112	9	160	8
Least Tern (*Sterna albifrons*)	--	35	2	--	18.5
Elegant Tern (*Thalasseus elegans*)	--	--	12	35	18.5
Royal Tern (*Thalasseus maximus*)	--	--	--	66	11
Caspian Tern (*Hydroprogne caspia*)	--	--	1	--	49.5
Kingfishers (Alcedinidae)					
Belted Kingfisher (*Megaceryle alcyon*)	--	--	1	4	40.5
TOTALS	2,311	1,564	1,680	3,564	

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[1] Rankings based on highest single sighting in 1978, regardless of the season. See Table 4 for details.

Table 2. Total numbers of marine birds, percents, and average per station for each season: 1978 compared to 1973/74

	January	April	July	October
A. 1978				
Numbers	2,311	1,564	1,680	3,564
Percent	25%	17%	19%	39%
Average number per station	74.5	50.5	54.2	115.0
B. 1973/74[1]				
Numbers	10,276	2,539	2,982	11,111
Percent	38%	9%	11%	41%
Average number per station	214.1	52.9	62.1	231.5

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[1] Data from Table 8.2 of the 1973/74 report (AHF, 1976).

Table 3. Average number of individuals seen per survey over stations X50 through X80

Common Name[1]	1973/74[2]	1978[3]	Difference[4]
Common Loon	3.2	2.0	-
Arctic Loon	0.8	5.8	+
Red-throated Loon	1.9	14.5	+
Horned Grebe	0.3	1.3	+
Eared Grebe	12.3	19.3	+
Western Grebe	9.1	100.3	+
Pied-billed Grebe	0.2	0	-
Brown Pelican	216.8	313.8	+
Double-crested Cormorant	29.0	51.8	+ (A+)
Brandt's Cormorant	1.9	2.5	+
Pelagic Cormorant	0.8	3.3	+
Great Blue Heron	5.2	7.0	+
Black-crowned Night Heron	0.1	3.3	+
Snowy Egret	0.1	0	-
Black Brant	0.1	0	-
Pintail	0	1.0	+
Cinnamon Teal	6.2	16.3	+
Mallard	0.2	0	-
Lesser Scaup	6.5	7.3	+
Canvasback	0	0.3	+
Surf Scoter	813.6	257.8	- (A+)
Common Scoter	1.1	0.3	-
White-winged Scoter	2.1	0.3	-
Ruddy Duck	0.1	0	-

Table 3 (cont.)

Common Name[1]	1973/74[2]	1978[3]	Difference[4]
Common Merganser	1.5	0	-
Red-breasted Merganser	3.5	2.0	-
American Coot	0.2	0.5	+
Black Oystercatcher	0	0.5	+
Killdeer	3.2	1.3	-
Snowy Plover	0.7	0.3	-
Semipalmated Plover	0.1	0.0	-
Black-bellied Plover	57.2	22.3	-
Surfbird	12.2	2.5	-
Ruddy Turnstone	17.7	12.5	-
Black Turnstone	23.7	9.7	-
Whimbrel	0.5	2.0	+
Spotted Sandpiper	4.4	5.8	+
Wandering Tattler	3.7	10.8	+
Willet	40.1	17.0	-
Least Sandpiper	7.3	2.3	-
Dunlin	0.4	1.0	+
Long-billed Dowitcher	1.4	0	-
Western Sandpiper	18.6	0.5	-
Marbled Godwit	3.5	0.5	-
Sanderling	262.9	22.8	-
Pomarine Jaeger	0.1	0	-
Parasitic Jaeger	0.4	0	-
Glaucous Gull	0.6	0.0	-

Table 3 (Cont.)

Common Name[1]	1973/74[2]	1978[3]	Difference[4]
Glaucous-winged Gull	10.9	2.5	-
Western Gull	1,267.4	310.8	-
Thayer's Gull	1.0	0	-
Herring Gull	50.1	13.3	-
California Gull	374.2	15.8	-
Ring-billed Gull	231.2	73.5	- (A-)
Mew Gull	104.4	73.3	-
Bonaparte's Gull	211.4	64.0	- (A-)
Heermann's Gull	1,619.4	634.3	- (A-)
Black-legged Kittiwake	29.0	10.0	-
Forster's Tern	159.5	81.5	- (A-)
Common Tern	0.3	0	-
Least Tern	4.4	9.3	+
Elegant Tern	14.6	11.8	-
Caspian Tern	10.8	0.25	-
Royal Tern	0	16.5	+
Common Murre	0.4	0	-
Belted Kingfisher	1.4	1.3	-

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[1] See Table 1 for scientific names

[2] Average of 14 surveys in 1973/74.

[3] Average of 4 surveys in 1978.

[4] "-" indicates fewer birds were seen in 1978 than in 1973/74
"+" means more birds were seen in 1978 than in 1973/74
A = Audubon survey of adjacent areas, + or -.

Table 4. Rankings of water and shore birds based on highest single day of observation in 1978.[1]

Rank	Species[2]	Number of individuals at highest sighting	Season of highest sighting[3]
1	Heermann's Gull	1,564	F
2	Brown Pelican	753	F
3	Western Gull	439	Sp
4	Surf Scoter	324	F
5	Mew Gull	292	W
6	Western Grebe	225	W
7	Ring-billed Gull	183	W
8	Forster's Tern	160	F
9	Bonaparte's Gull	134	W
10	Double-crested Cormorant	73	Sp
11	Royal Tern	66	F
12	Cinnamon Teal	65	W
13	Eared Grebe	55	W
14.5[4]	Herring Gull	52	W
14.5	Sanderling	52	W
16	California Gull	45	Sp
17	Black-bellied Plover	44	W
18.5	Elegant Tern	35	Sp
18.5	Least Tern	35	F
20	Red-throated Loon	30	Sp
21	Lesser Scaup	29	W

Table 4 (Cont.)

Rank	Species[2]	Number of individuals at highest sighting	Season of highest sighting[3]
22.5	Willet	27	F
22.5	Black-legged Kittiwake	27	Sp
24	Wandering Tattler	24	F
25	Ruddy Turnstone	23	Sp
26	Arctic Loon	21	Sp
27	Great Blue Heron	19	W
28	Black-crowned Night Heron	13	Su
29	Glaucous-winged Gull	10	W
30.5	Black Turnstone	9	W, Su
30.5	Spotted Sandpiper	9	Sp
33[4]	Red-brested Merganser	6	W
33	Whimbrel	6	Sp
33	Brandt's Cormorant	6	Su
36.5	Pelagic Cormorant	5	W, Sp
36.5	Common Loon	5	Sp
36.5	Least Sandpiper	5	W
36.5	Killdeer	5	F
40.5	Pintail	4	W
40.5	Surfbird	4	Sp
40.5	Dunlin	4	F
40.5	Belted Kingfisher	4	F
43	Horned Grebe	3	W
45	Black Oystercatcher	2	Sp

Table 4 (Cont.)

Rank	Species[2]	Number of individuals at highest sighting	Season of highest sighting[3]
45	Western Sandpiper	2	F
45	American Coot	2	F
49.5	Canvasback	1	W
49.5	Marbled Godwit	1	W,Su
49.5	Black Scoter	1	Sp
49.5	White-winged Scoter	1	Su
49.5	Snowy Plover	1	Sp
49.5	Caspian Tern	1	Su

---

[1] Details of seasonal sightings are given in Table 1.

[2] Scientific names are given in Table 1.

[3] W = winter, Sp = spring, Su = summer, F = fall.

[4] Fractions and duplicate numbers indicate ties. For example, species tied for 14th place instead of being both assigned the same rank, or one arbitarily assigned 14 and the other 15, are both assigned 14.5.

Table 5. Numbers of species and numbers of individual water and shore birds at each station in 1978.

Station	January		April		July		October	
	Species	Indiv.	Species	Indiv.	Species	Indiv.	Species	Indiv.
50	15	543	10	51	2	8	15	188
51	7	29	7	64	0	0	2	5
52	6	31	6	45	0	0	7	34
53	--	--	5	15	4	6	1	2
54	8	51	7	33	4	25	5	10
55	10	238	5	12	2	59	3	62
56	11	109	13	133	5	103	9	17
57	7	9	3	5	0	0	9	52
58	11	103	7	141	4	74	8	943
59	6	13	9	35	7	53	9	330
60	3	3	4	99	4	110	4	26
61	1	1	9	71	2	8	3	16
62	15	114	13	108	10	206	11	281
63	4	14	3	3	0	0	0	0
64	8	59	8	30	4	46	6	77
65	8	42	5	8	3	64	1	2
66	--	--	--	--	--	--	0	0
67	4	8	2	2	1	2	3	5
68	9	36	4	40	3	4	10	257
69	5	12	8	18	1	1	7	8
70	4	67	11	150	5	107	6	315
71	23	156	10	66	12	199	19	491
72	8	58	3	19	3	82	4	123
* 73	7	25	2	3	0	0	1	1
74	8	48	6	19	7	103	3	108
75	21	225	18	125	12	84	13	36
76	5	34	4	7	3	63	4	79
77	9	95	6	27	3	10	6	26
78	5	54	11	69	2	14	4	11
79	6	68	7	63	1	1	5	40
80	9	68	11	103	4	247	5	19
Average per site	8.38	79.68	7.23	52.13	3.60	55.97	5.90	114.97

* Areas influenced by effluent.

Table 6. Species of water and shore-birds recorded at the sewer outfall boil (station X74) in 1978.

Species	January	April	July	October
Red-throated Loon	5	0	0	0
Common Loon	0	0	3	0
Western Grebe	1	1	0	0
Eared Grebe	3	0	0	4
Brown Pelican	0	1	14	0
Double-crested Cormorant	0	2	0	0
Brandt's Cormorant	0	0	3	0
Surf Scoter	8	6	70	100
Lesser Scaup	7	0	0	0
Cinnamon Teal	14	0	0	0
Heermann's Gull	0	0	10	0
Western Gull	0	8	0	0
Bonaparte's Gull	9	0	0	0
Forster's Tern	1	1	0	4
Elegant Tern	0	0	1	0
Least Tern	0	0	2	0
No. of Species	8	6	7	3
No. of individuals	48	19	103	108

Table 7. Totals and average numbers of species of marine birds at station X74 and X75 combined during 1973/74 and 1978.

Common Name[1]	1973/74		1978	
	Total	Average[2]	Total	Average[2]
Common Loon	--	--	3	0.75
Red-throated Loon	--	--	6	1.50
Eared Grebe	7	0.50	53	13.25
Western Grebe	--	--	14	3.50
Brown Pelican	50	3.57	54	13.50
Double-crested Cormorant	7	0.50	83	20.75
Pelagic Cormorant	--	--	8	2.00
Brandt's Cormorant	--	--	4	1.00
Great Blue Heron	--	--	1	0.25
Cinnamon Teal	9	0.64	14	3.50
Lesser Scaup	5	0.36	24	6.00
Canvasback	--	--	1	0.25
Surf Scoter	247	17.64	207	51.75
Killdeer	1	0.07	--	--
Snowy Plover	--	--	1	0.25
Black-bellied Plover	55	3.93	13	3.25
Surfbird	--	--	5	1.25
Ruddy Turnstone	6	0.43	13	3.25
Black Turnstone	--	--	4	1.00
Whimbrel	--	--	4	1.00
Spotted Sandpiper	--	--	9	2.25

Table 7 (continued)

Common Name[1]	1973/74 Total	1973/74 Average[2]	1978 Total	1978 Average[2]
Wandering Tattler	--	--	9	2.25
Willet	167	11.93	12	3.00
Least Sandpiper	3	0.21	--	--
Dunlin	4	0.29	--	--
Western Sandpiper	14	1.00	--	--
Sanderling	2967	211.93	41	10.25
Marbled Godwit	1	0.07	--	--
Long-billed Dowitcher	7	0.50	--	--
Western Gull	1699	121.36	73	18.25
Herring Gull	--	--	9	2.25
California Gull	159	11.36	11	2.75
Ring-billed Gull	1783	127.36	5	1.25
Mew Gull	6	0.43	--	--
Bonaparte's Gull	997	71.21	9	2.25
Heermann's Gull	267	19.07	35	8.75
Glaucous-winged Gull	34	2.43	1	0.25
Glaucous Gull	2	0.14	--	--
Thayer's Gull	4	0.29	--	--
Black-legged Kittiwake	1	0.07	--	--
Forster's Tern	103	7.36	18	4.50
Least Tern	--	--	2	0.50
Elegant Tern	--	--	1	0.25

Table 7 (continued)

Common Name[1]	1973/74		1978	
	Total	Average[2]	Total	Average[2]
Caspian Tern	336	24.00	--	--
Belted Kingfisher	--	--	1	0.25
Total Nos.	8941	638.64	748	187.00
Total nos. excluding Sanderling	5974	426.71	707	176.75
Total Species	28	--	34	--

[1] Scientific names are given in Table 1.

[2] Averages are calculated by dividing the total number of birds by the number of observation periods: 14 for 1973/74 and 4 for 1978.

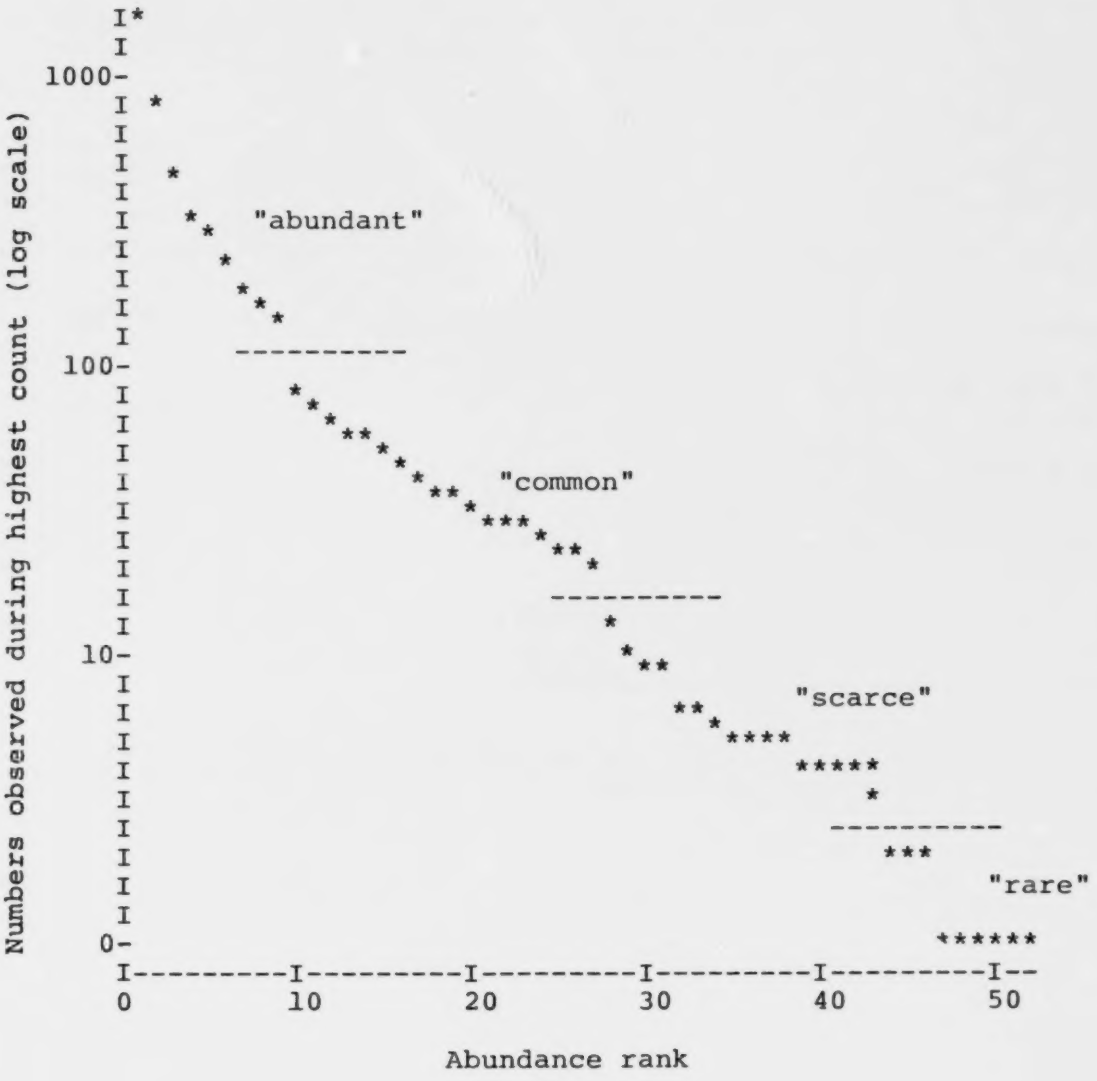

Figure 2. Numbers of individuals of each species observed during the day of the highest sighting (Table 4) plotted against rank. Breaks in the trend appear at about 100 and at 15 individuals, allowing separation into arbitrary categories labelled "abundant," "common," and "scarce." A separation between "scarce" and "rare" is arbitrary, placed at between two and three individuals.

Table 8. **Summary of Bird Watching, January-November 1978. Los Angeles/Long Beach Harbors.**

	March	April	May	June	July	August	September	October	November
Cabrillo Beach (1)	2 Gulls 7 Other	16 Gulls 7 Other	1 Gull 1 Tern 2 Other	3 Gulls 2 Terns	11 Gulls 2 Peli. 1 Other	2 Gulls 2 Others	13 Gulls 15 Peli.	24 Gulls 50 Terns 18 Peli. 1 Corm.	13 Gulls 14 Other 3 Terns
San Pedro Market (2)	1 Peli. 3 Other	3 Gulls 4 Other	3 Gulls	--	--	1 Gull	1 Gull	23 Gulls 11 Terns 1 Corm.	43 Gulls 17 Peli.
Ports O'Call (3)	4 Gulls 12 Other	4 Gulls 5 Other	1 Gull 1 Other	2 Corm.	1 Gull	2 Gulls	20 Gulls	5 Gulls 13 Other	2 Gulls
Outfall Area (4)	1 Gull	1 Gull 15 Corm.	6 Gulls	10 Gulls 2 Other	17 Gulls 4 Peli.	5 Gulls 2 Corm. 3 Peli.	1 Corm.	53 Gulls 36 Terns 30 Peli. 18 Other	16 Gulls 16 Terns 25 Other 8 Peli. 1 Corm.
Fish Harbor (5)	5 Gulls 26 Other	33 Gulls 19 Other 1 Corm.	2 Gulls 5 Other	4 Gulls 3 Other	8 Gulls 5 Other	1 Tern 5 Other	1 Gull	3 Gulls 4 Other	1 Gull 4 Other
Navy Mole (6)	8 Gulls 1 Peli. 99 Other 225 Corm.	184 Gulls 29 Corm. 102 Other 1 Peli.	20 Gulls 32 Corm. 56 Other	57 Gulls 29 Corm. 37 Other	17 Gulls 13 Corm. 6 Peli.	37 Gulls 23 Corm. 46 Peli. 1 Tern 5 Other	125 Gulls 53 Corm. 44 Peli. 3 Terns	76 Gulls 53 Peli. 42 Corm. 7 Other 2 Terns	616 Gulls 130 Terns 227 Other 2 Corm.
Queen Mary (7)	1 Peli. 2 Other	5 Gulls 6 Other	10 Gulls 1 Corm. 5 Other	3 Gulls 2 Peli. 4 Other	2 Gulls 2 Peli.	--	4 Gulls	2 Peli.	1 Peli. 5 Other
Los Angeles River (8)	1 Gull 24 Other	4 Other	2 Corm. 2 Other	--	5 Other	25 Other	--	--	7 Other

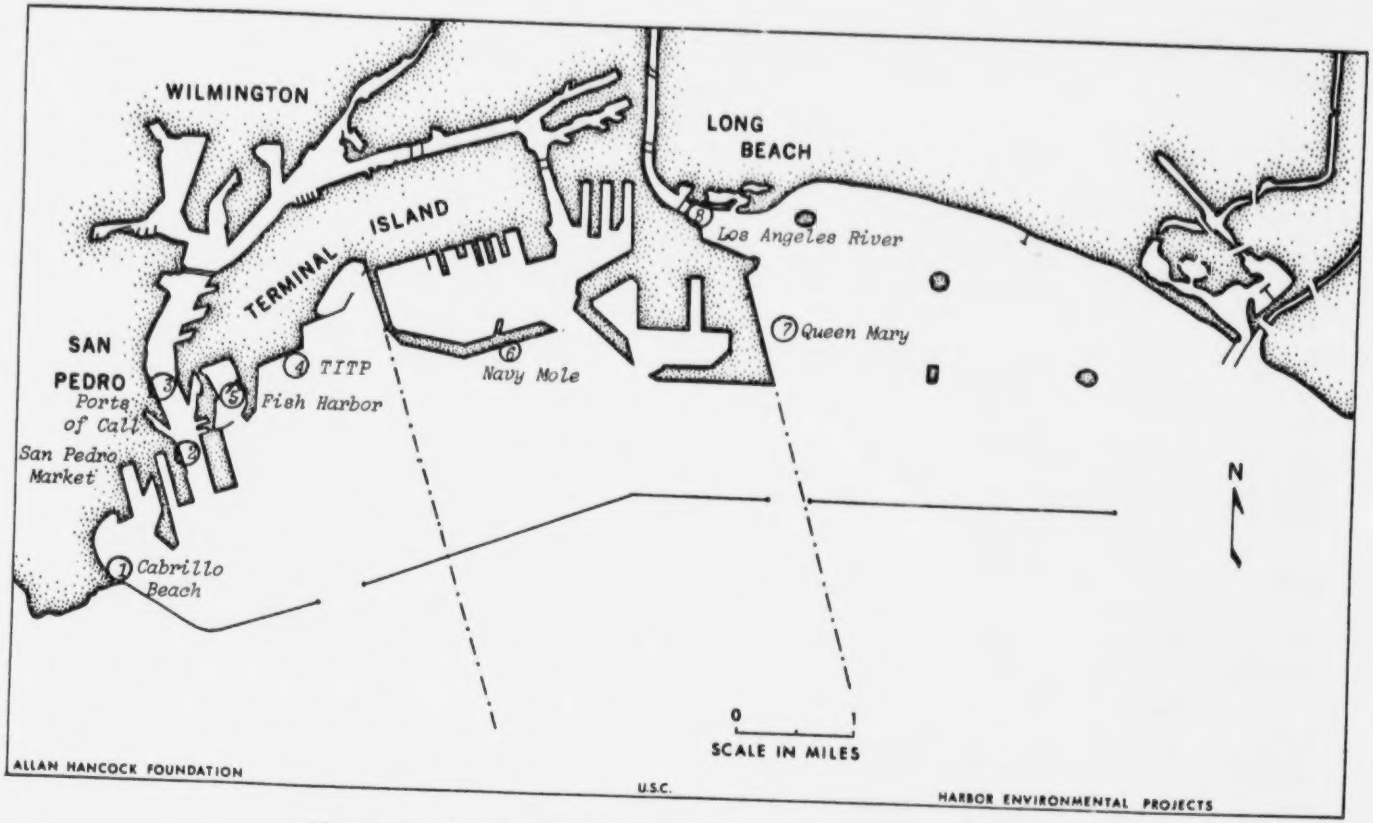

Figure 3. Locations of Monthly Surveys of Common Birds.

PHYTOPLANKTON PRIMARY PRODUCTIVITY IN OUTER LOS ANGELES HARBOR, 1976-1978

INTRODUCTION

Studies of phytoplankton primary productivity, photosynthetic pigments and assimilation ratios have been carried out in Los Angeles-Long Beach Harbors since 1972. These studies, usually involving monthly sampling, have been carried out at a series of stations that covered the entire harbor area. Data from these studies, and discussion of the trends shown in the distribution of data in time and space, are contained in reports by Soule and Oguri (1973, 1978), Oguri (1974, 1976), Oguri, *et al.* (1975), Emerson (1976) and Allan Hancock Foundation (1976). The following review is drawn from the studies made while the two cannery waste effluents and TITP primary wastes were entering the harbor. Cannery loads varied from 2-30 mgd (million gallons/day) and TITP was rated at 10 mgd but flow meters were not used routinely.

The seasonal patterns of the productivity, pigments and assimilation ratio that occurred in the harbor between 1972 and 1976 generally paralleled the pattern for the open coastal waters of the area, although at a substantially higher level. A spring bloom, occurring sometime between March and May, would be followed by a brief reduction in productivity. Late summer and early fall were often marked by secondary blooms, usually of populations dominated by dinoflagellates. This, in turn, was followed by a drop in phytoplankton populations and activities to the winter minima.

The dinoflagellate blooms mentioned above were usually seasonal in nature, occurring only during the warmer months. These varied from small localized occurrences, barely detectable by appearance, to harbor-wide episodes in which the concentration of organisms was intense enough to discolor the waters. The latter episodes were relatively infrequent, and sometimes included all of the adjacent coastal waters and Santa Monica Bay. No large blooms have occurred since 1974.

Values for productivity and chlorophyll *a* within the harbor were generally higher than those prevailing in adjacent open coastal waters. These differences were most pronounced during periods of active blooming in the spring or summer and fall. Assimilation ratios were more similar on both sides of the breakwater and followed the seasonal trends described above.

Within the harbor the inner channels showed higher average values for productivity and chlorophyll *a* than did outer harbor stations. Areas with a persistent input of enrichment were also found to be more productive. These areas included the area around the mouth of the Los Angeles River and, until recently, the outer harbor area affected by the discharges from the Terminal Island Treatment Plant and the cannery outfalls. The treatment plant discharged primary treated wastes until mid-April 1977, when the plant converted to full secondary treatment. The waste waters from the canneries were phased into the treatment plant beginning in October 1977, with the last one being diverted into the plant in January 1978.

The impact of localized traumatic occurrences on the harbor phytoplankton and their activities was studied closely in the aftermath of the M.V. Sansinena incident in which the tanker exploded and burned at dockside, releasing an unknown quantity of Bunker C oil into the harbor. Monitoring of the area indicated that there was an increase in productivity in the immediate vicinity of the incident that persisted for about two weeks after the explosion.

The conversion of the Terminal Island Treatment Plant to full secondary treatment, starting in April 1977, and the diversion of the cannery waste discharges into the plant for treatment, completed in January 1978, represent a continuing alteration rather than traumatic disruption of the ecosystem. The continuous removal of organics and other substances and the alteration of others during TITP treatment of the wastes changes the character of the discharge and, therefore, the character of the receiving waters. The plant initially experienced some problems in accepting the variable high salinities and BOD levels of the cannery effluents. These problems were apparently stabilized by the late winter of 1978. However, processing difficulties led to a major plant upset starting in June and lasting into September 1978. During this period the effluent contained excessive suspended solids and was highly turbid.

The present report documents concurrent changes in phytoplankton productivity, pigments and assimilation in the vicinity of the discharge during 1976 through 1978 and updates the earlier reports on these parameters in the harbor area.

METHODS

Samples of surface waters were collected from a series of stations in outer Los Angeles Harbor in non-metallic samplers, on a monthly basis. The stations are shown in Figure 1.

A portion of the water sample was filtered through a Millipore HA filter to remove the cells. A small portion of a $MgCO_3$ suspension was added to the water to retard breakdown of the pigments. After drying, the pigments were extracted from the cells on the filter into 90% acetone. The absorbance of the pigments in the acetone extract was measured in a spectrophotometer and concentrations of the pigments were calculated according to the method and formulae of Strickland and Parsons (1972).

Another portion of the water sample was used to fill two clear and two opaque 125 ml glass stoppered bottles. The bottles were then held until a standard time for starting incubation. To each of these, a known quantity of radioactive carbon (^{14}C) as a carbonate was added. These bottles were then incubated for three hours in an artificially illuminated incubator with flow-through sea water to hold the temperature to ambient conditions. The contents of the bottles were then filtered and the filters were dried. Upon return to the laboratory the amount of radiocarbon taken up by the cells was determined and these data were used to calculate milligrams of carbon fixed by the phytoplankton per hour of incubation per cubic meter of water sampled.

Assimilation ratios were calculated by dividing the values determined for productivity by the values determined for chlorophyll *a* concentrations.

Productivity values reflect the ability of the phytoplankton present to produce organic matter photosynthetically under ambient conditions existing in the waters sampled. This reflects not only the presence of fertilizer salts but also of possible inhibiting or toxic substances.

Chlorophyll *a* values are considered to be a measure of the size of the phytoplankton population present. Although chlorophyll content varies for cells of different species and also within the same species, it is considered an acceptable measure of the functional standing crop, since productivity is photosynthetic under the conditions of measurement.

Assimilation ratio calculated as stated above represents an index to the physiological state of the photosynthetic population. The effect of limiting, inhibiting, toxic or stimulating substances on these organisms is indicated by this value.

RESULTS

The data from samples collected in 1976, 1977 and 1978 are presented in Tables 1, 2 and 3. Productivity values, shown as PROD in the tables, are as milligrams of carbon fixed per hour of incubation per cubic meter of water sampled. The chlorophyll *a* values are designated CHLA in the tables and the units are milligrams per cubic meter of water sampled. The assimilation ratios are designated ASMA in the tables and have no units.

Data were averaged for stations A1, A2, A3, A4, A7, and A8 and these averages for each year were plotted to show chlorophyll *a* concentrations (Figure 2), productivity (Figure 3), and assimilation ratios (Figure 4).

The chlorophyll *a* values presented in the tables and illustrated in Figure 2 show a repetitive cycle for the sequence of occurrences with differences in magnitude and timing of peaks. The spring bloom in 1976 was more pronounced and occurred earlier than in 1977 and 1978. In 1978 it was much reduced. In the summer, chlorophyll *a* values again peaked in all three years, and a third peak occurred in the fall or early winter. Inspection of the tabulated data points out that for all three years chlorophyll *a* values were higher in the harbor than at station A1, outside the harbor, but that the same sequence occurred in both places. This suggests that the seasonal influences determining population size are operational within the harbor as well as outside, but the harbor environment permits the development of increased populations.

The productivity values for 1976 and 1977, shown in Figure 3, reveal the same trends with peaks in spring, summer and fall. However, in 1977 the spring and fall peaks were substantially lower than those for 1976, although the summer peak was similar. The data for 1978 show considerably less productivity, although there is some evidence of the same trends shown for 1976 and 1977.

Figure 4 shows the assimilation ratios for the three years. As with chlorophyll *a* and productivity values, 1976 and 1977 showed similar trends, differing primarily in magnitude and timing. The ratios for 1977 were lower than those for 1976 and, in September, showed a sharp reduction not evident in the ratios for 1976. The 1978 data seem to bear little relationship to those for the earlier years. These values are very low, suggesting that the populations are being stressed, particularly in the late spring and summer.

CONCLUSIONS

The relatively similar annual cycles of chlorophyll *a* concentrations suggest that the timing of events in the harbor have not significantly altered the development of phytoplankton populations. However, the productivity and assimilation ratio values indicate that the populations have either been inhibited or were limited in their ability to photosynthesize in 1977 and, more severly so in 1978.

The conversion of the Terminal Island Treatment Plant to full secondary treatment in the spring of 1977 was followed by levels of productivity and assimilation that were substantially lower than in 1976, although the chlorophyll *a* levels were similar. The diversion of the cannery wastes into the treatment plant in 1977 and early 1978 was followed by further reductions in productivity and assimilation ratio, particularly in the peak periods.

The plant upset at the Terminal Island Treatment Plant in 1978 occurred during a time of year when assimilation ratio is usually high. However, in 1978 the lower values that occurred earlier in the year persisted. It is not clear whether this might be related to the plant upset or to the change in effluents discharged in the harbor. It seems clear, however, that there has been a three- to four-fold drop in productivity at peak periods, and as much as a seven-fold drop in assimilation ratio.

The driving mechanisms for phytoplankton blooms are still not understood after years of research (LoCicero, 1975). In the early 1970's the thesis was that natural runoff of humic acid (iron) was causative; later hormones (giberellic acid) were investigated. There appears to be no correlation between rainfall in the Los Angeles Basin and phytoplankton blooms, but the urban dry weather drainage at the Los Angeles River mouth seems to cause the presence of small patchy blooms almost year around. Oguri, Soule, Juge and Abbott (1975) have postulated that the relationship is to bacterial metabolism; the 30-fold drop in bacteria in 1978 might explain the drop in productivity and assimilation ratio. The river mouth is an area of high bacterial counts (AHF, 1976).

LITERATURE CITED See Section VI

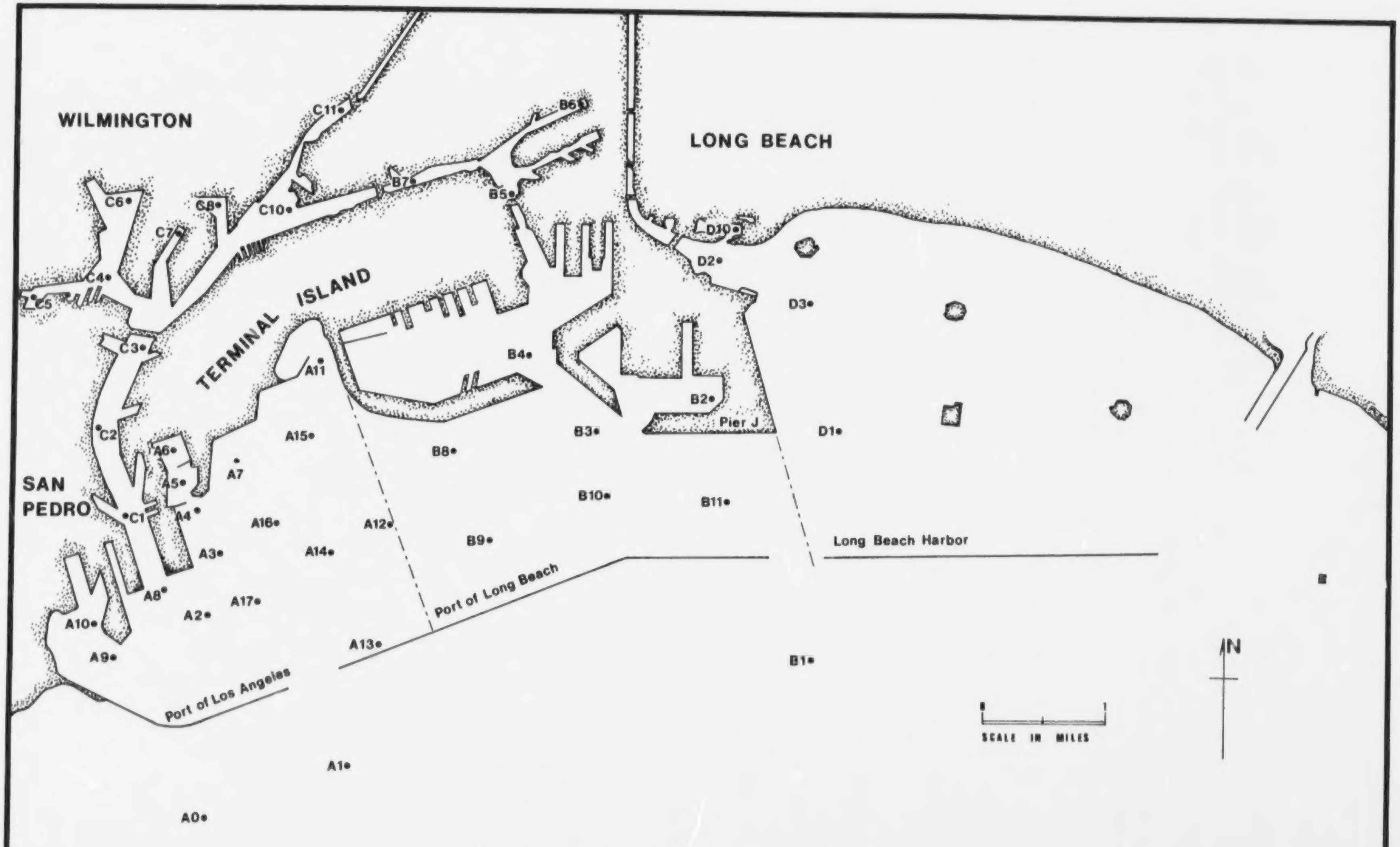

Figure 1. Station locations.

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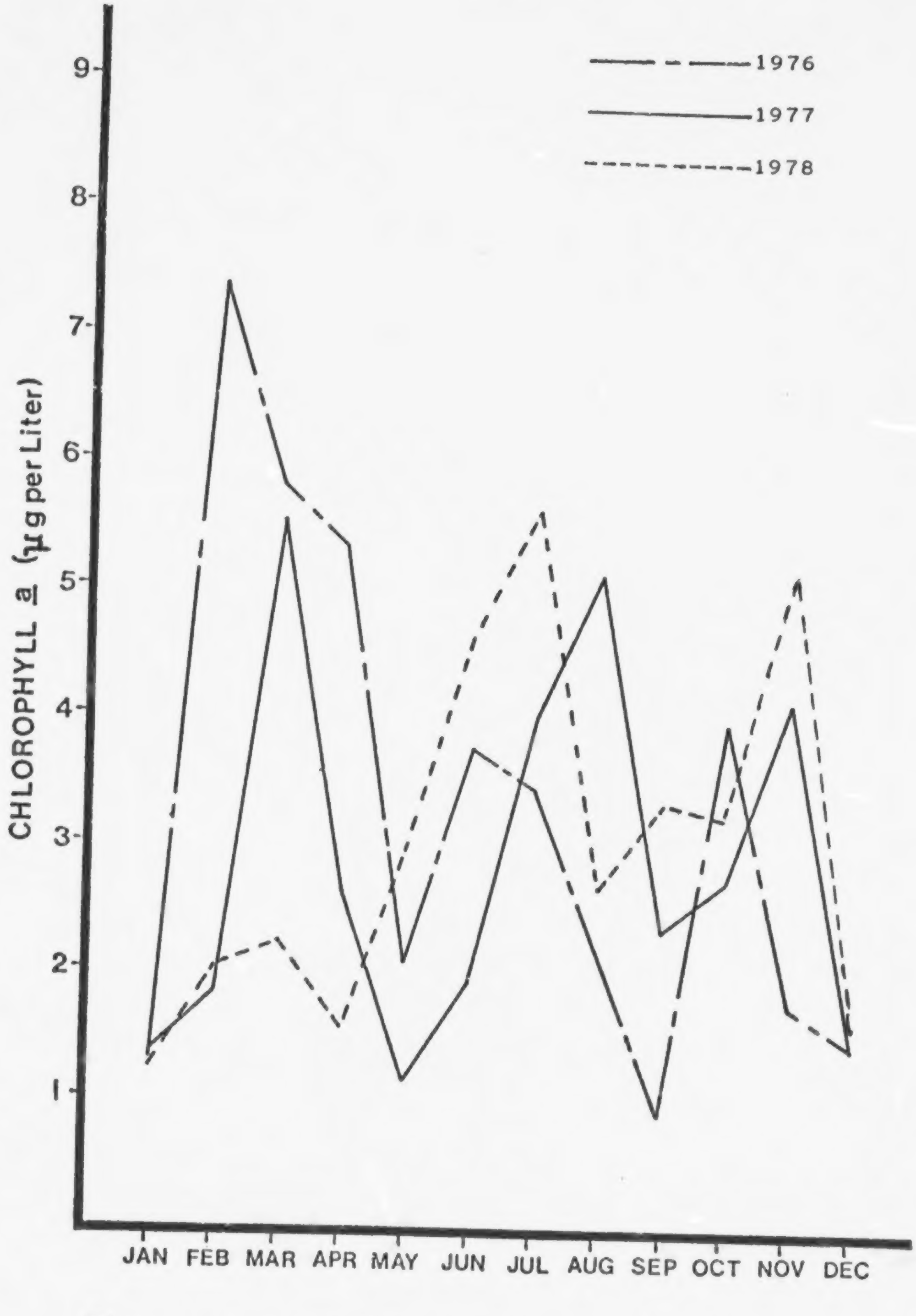

Figure 2. Chlorophyll *a* concentrations 1976-1978.

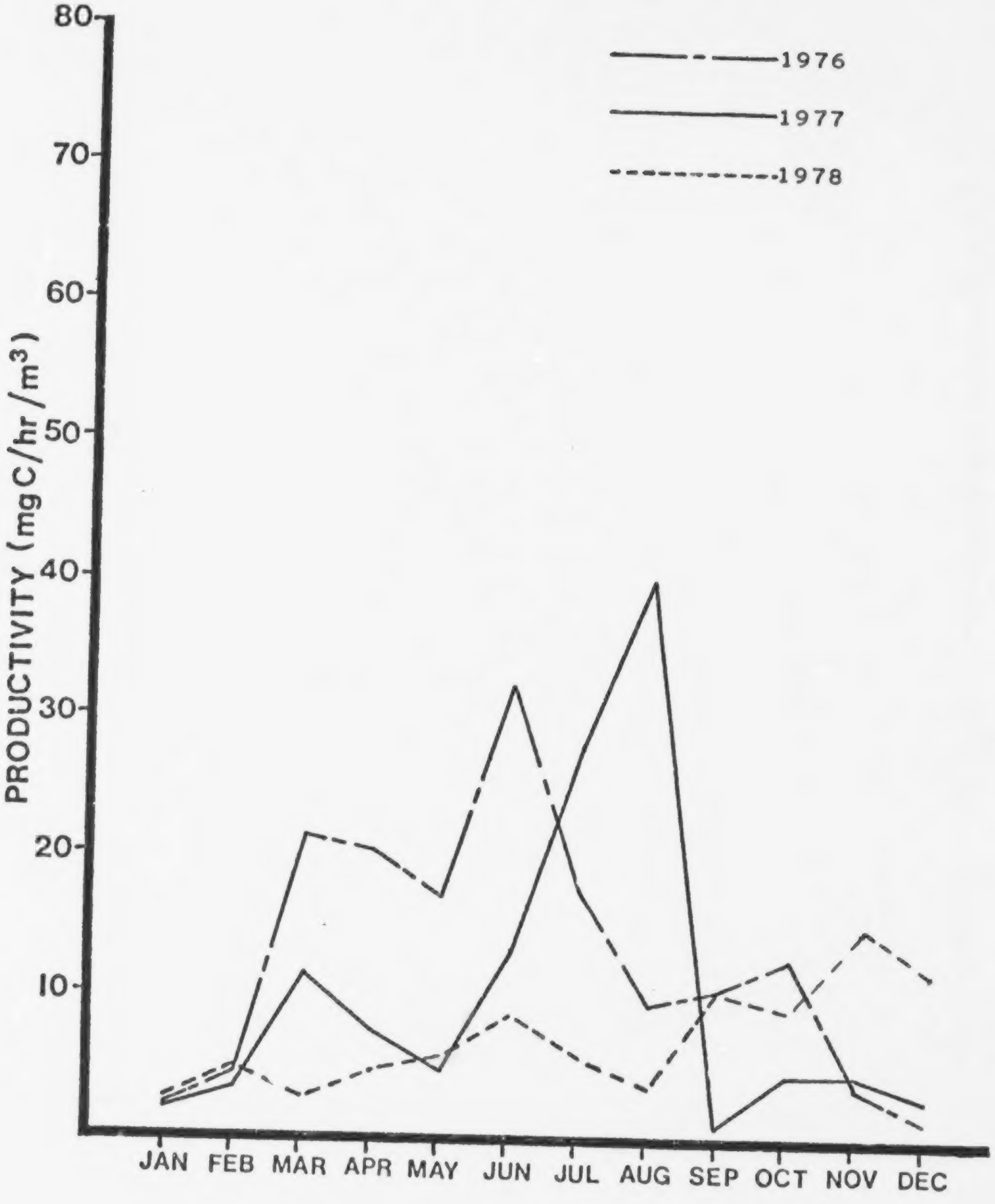

Figure 3. Primary productivity 1976-1978.

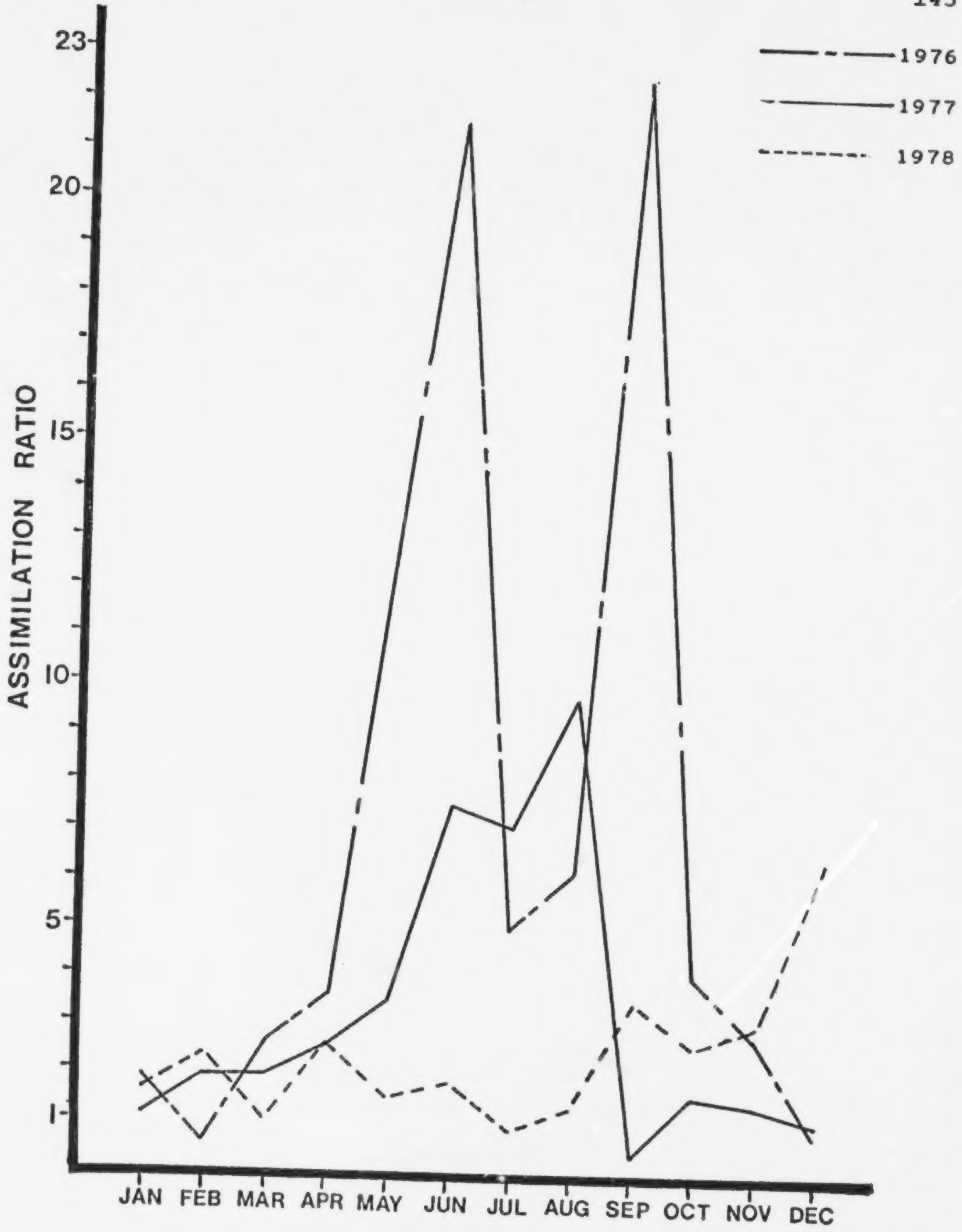

Figure 4. Assimilation ratio 1976-1978.

TABLE 1.

1976 PRODUCTIVITY, CHLOROPHYLL A, AND ASSIMILATION RATIO A.

		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
A1	PROD	1.61	3.63	4.65	14.53	22.25	50.90	2.56	2.57	16.85	2.88	1.72	0.28
	CHLA	0.62	5.38	4.55	4.24	1.01	0.66	0.69	0.21	0.23	0.58	0.63	0.68
	ASMA	2.60	0.67	1.02	3.43	22.03	77.12	3.71	12.24	73.13	4.97	2.73	0.41
A2	PROD	2.44	7.53	5.33	27.46	16.39	****	8.76	3.86	13.39	19.55	4.67	0.94
	CHLA	1.15	10.46	4.50	6.69	1.40	1.52	4.74	2.25	****	8.31	****	0.82
	ASMA	2.12	0.72	1.18	4.10	11.71	****	1.85	1.72	****	2.35	****	1.15
A3	PROD	4.79	3.97	6.36	27.49	4.42	3.29	24.23	4.97	4.51	22.91	2.32	1.60
	CHLA	1.35	8.45	4.47	5.64	1.30	5.49	3.20	3.39	1.97	2.84	2.17	1.10
	ASMA	3.55	0.47	1.42	4.87	3.40	0.60	7.60	1.47	2.29	8.07	1.07	1.45
A4	PROD	1.04	5.37	104.78	31.53	22.32	8.48	44.01	3.86	6.78	15.75	6.27	2.68
	CHLA	1.39	7.17	10.27	7.24	2.27	7.82	6.10	2.35	0.54	4.99	2.71	1.75
	ASMA	0.75	0.75	10.20	4.35	9.83	1.08	7.21	1.64	12.56	3.16	2.31	1.53
A7	PROD	1.57	1.23	2.46	8.70	22.20	****	12.79	3.33	9.99	7.38	1.53	0.25
	CHLA	1.87	4.37	5.77	5.25	0.97	2.34	3.62	2.35	1.14	5.09	2.58	3.22
	ASMA	0.84	0.28	0.43	1.66	22.89	****	3.53	1.42	8.76	1.45	0.59	0.08
A8	PROD	1.40	5.00	4.59	12.20	15.83	38.23	15.32	37.68	10.32	9.12	5.41	0.47
	CHLA	1.73	8.73	4.13	3.24	3.49	4.85	2.45	1.99	0.63	2.08	0.76	1.05
	ASMA	0.81	0.57	1.11	3.77	4.54	7.88	6.25	18.93	16.38	4.38	7.12	0.45
A9	PROD	5.27	6.50	4.40	17.12	29.07	34.33	10.37	6.61	15.50	25.30	7.11	3.46
	CHLA	0.91	****	4.86	3.62	2.54	4.94	6.16	2.35	2.22	4.89	1.44	1.54
	ASMA	5.79	****	0.91	4.73	11.44	6.95	1.68	2.81	6.98	5.17	4.94	2.25
A11	PROD	2.70	4.01	9.96	32.77	9.56	15.17	6.73	0.37	2.98	16.90	8.59	1.98
	CHLA	1.28	7.59	8.10	5.49	2.40	4.80	1.92	2.84	1.19	3.73	0.84	1.06
	ASMA	2.11	0.53	1.23	5.97	3.98	3.16	3.51	0.13	2.50	4.53	10.23	1.87

VALUES OF **** REPRESENT DATA NOT AVAILABLE

TABLE 1. (CON'T)

1976 PRODUCTIVITY, CHLOROPHYLL A, AND ASSIMILATION RATIO A (CON'T)

		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
A12	PROD	4.23	3.95	7.01	31.62	23.98	7.27	15.39	2.43	5.14	14.75	4.63	4.58
	CHLA	1.20	6.39	7.88	10.42	*****	2.80	1.64	0.41	0.60	2.63	1.53	1.32
	ASMA	3.53	0.62	0.89	3.03	*****	2.60	9.38	5.93	8.57	5.61	3.03	3.47
C1	PROD	3.11	3.43	4.07	7.89	7.71	27.10	12.56	4.32	0.97	6.57	7.45	0.73
	CHLA	0.94	2.96	3.62	*****	1.20	4.83	2.23	0.99	0.67	2.43	1.49	1.14
	ASMA	3.31	1.16	1.12	*****	6.43	5.61	5.63	4.36	1.45	2.70	5.00	0.64
C2	PROD	3.15	2.78	3.86	10.56	8.28	27.05	10.68	23.80	3.56	16.23	7.50	0.30
	CHLA	0.68	2.08	2.96	*****	0.86	3.43	1.69	2.12	0.41	2.89	1.75	0.90
	ASMA	4.63	1.34	1.30	*****	9.63	7.89	6.32	11.23	8.68	5.62	4.29	0.33
C3	PROD	2.25	3.01	4.78	3.52	6.92	4.61	4.38	24.95	2.95	8.64	0.20	0.50
	CHLA	1.53	2.08	4.30	*****	0.75	2.49	1.14	0.92	1.05	2.46	1.54	1.03
	ASMA	1.47	1.45	1.11	*****	9.23	1.85	3.84	27.12	2.81	3.51	0.13	0.49

VALUES OF ***** REPRESENT DATA NOT AVAILABLE

TABLE 2.

1977 PRODUCTIVITY, CHLOROPHYLL A, AND ASSIMILATION RATIO A

		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
A1	PROD	1.27	4.38	2.18	1.25	10.26	4.28	4.54	9.73	0.23	1.77	0.66	0.53
	CHLA	0.77	1.31	1.52	0.34	*****	0.63	0.79	1.24	0.27	1.81	0.53	0.82
	ASMA	1.65	3.34	1.43	3.68	*****	6.79	5.75	7.85	0.85	0.98	1.25	0.65
											0.27*		
											0.30*		
											0.90*		
A2	PROD	0.94	2.77	14.66	22.36	4.59	14.29	30.52	51.50	0.67	7.60	4.49	1.17
	CHLA	0.91	1.13	6.82	6.39	1.55	1.02	4.21	5.25	2.09	2.84	2.55	0.52
	ASMA	1.03	2.45	2.15	3.50	2.96	14.01	7.25	9.81	0.32	2.68	1.76	2.25
											3.93*		
											1.49*		
											2.64*		
A3	PROD	0.59	1.82	28.72	*****	3.16	16.58	30.19	40.84	0.84	5.22	8.77	4.19
	CHLA	3.28	1.17	7.38	2.65	1.02	2.32	5.27	2.22	2.53	2.22	10.00	2.33
	ASMA	0.18	1.56	3.89	*****	3.10	7.15	5.73	18.40	0.33	2.35	0.88	1.80
											2.38*		
											2.09*		
											1.14*		
A4	PROD	1.41	6.02	3.57	2.05	2.49	11.52	31.25	67.08	0.27	6.14	6.95	3.19
	CHLA	1.22	2.82	2.57	2.77	1.31	2.27	5.98	13.80	2.00	3.62	*****	1.71
	ASMA	1.16	2.13	1.39	0.74	1.90	5.07	5.23	4.86	0.14	1.70	*****	1.87
											16.77*		
											9.38*		
											1.79*		
A7	PROD	1.37	0.49	4.80	1.09	4.60	15.50	31.12	28.89	0.97	0.50	0.49	2.98
	CHLA	0.99	2.89	8.51	1.26	1.02	2.96	4.23	4.48	4.54	3.32	3.92	2.37
	ASMA	1.38	0.17	0.56	0.87	4.51	5.24	7.36	6.45	0.21	0.15	0.13	1.26
											1.52*		
											2.82*		
											0.54*		

*SPECIAL REPORT DATED OCTOBER 12, 1977

VALUES OF ***** REPRESENT DATA NOT AVAILABLE

TABLE 2. (CON'T)
1977 PRODUCTIVITY, CHLOROPHYLL A, AND ASSIMILATION RATIO A (CON'T)

		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
A8	PROD	1.00	2.98	13.91	10.37	4.34	15.89	40.76	43.03	0.82	3.71	4.00	0.40
	CHLA	1.03	1.56	6.56	2.49	0.83	2.33	3.64	3.90	2.66	****	3.72	0.91
	ASMA	0.97	1.91	2.12	4.16	5.23	6.82	11.20	11.03	0.31	****	1.08	0.44
											3.77*		
											2.29*		
											1.65*		
A9	PROD	1.31	3.05	6.04	10.09	4.16	9.56	18.38	39.11	0.45	4.23	3.65	0.62
	CHLA	1.14	1.34	2.36	5.78	0.82	1.67	3.50	1.76	2.31	4.47	2.76	0.98
	ASMA	1.15	2.28	2.52	1.75	5.07	5.72	5.25	22.22	0.19	0.95	1.32	0.63
											3.77*		
											4.60*		
											0.82*		
A10	PROD	1.29	3.42	16.18	7.99	3.39	12.95	13.80	35.73	0.20	****	****	****
	CHLA	0.30	1.34	4.26	4.00	1.55	2.42	4.10	3.01	3.06	****	****	****
	ASMA	4.30	2.55	3.80	2.00	2.19	5.35	3.37	11.87	0.07	****	****	****
A11	PROD	0.86	3.82	19.41	****	8.59	14.38	11.02	39.83	1.00	****	****	****
	CHLA	0.85	1.49	6.88	2.62	****	2.20	3.38	2.67	2.63	****	****	****
	ASMA	1.01	2.56	2.82	****	****	6.54	3.26	14.92	0.38	****	****	****
A12	PROD	0.67	1.72	****	4.20	2.84	11.17	9.74	12.47	0.28	2.01	1.43	1.67
	CHLA	0.72	1.47	4.70	2.13	****	2.22	4.82	2.09	2.14	2.43	0.76	2.62
	ASMA	0.93	1.17	****	1.97	****	5.03	2.02	5.97	0.13	0.83	1.88	0.64
											1.78*		
											1.72*		
											1.03*		

*SPECIAL REPORT DATED OCTOBER 12, 1977
VALUES OF **** REPRESENT DATA NOT AVAILABLE

TABLE 2 . (CON'T)

1977 PRODUCTIVITY, CHLOROPHYLL A, AND ASSIMILATION RATIO A (CON'T)

		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
A13	PROD	****	****	****	****	****	****	****	****	****	10.67	1.93	2.15
	CHLA	****	****	****	****	****	****	****	****	****	5.26	0.62	1.18
	ASMA	****	****	****	****	****	****	****	****	****	2.03	3.11	1.82
											3.96*		
											1.56*		
											2.54*		
A14	PROD	****	****	****	****	****	****	****	****	****	1.47	2.00	2.50
	CHLA	****	****	****	****	****	****	****	****	****	1.67	1.16	2.51
	ASMA	****	****	****	****	****	****	****	****	****	0.88	1.72	1.00
											1.65*		
											2.03*		
											0.81*		
A15	PROD	****	****	****	****	****	****	****	****	****	2.78	4.02	36.30
	CHLA	****	****	****	****	****	****	****	****	****	2.19	1.19	35.86
	ASMA	****	****	****	****	****	****	****	****	****	1.27	3.38	1.01
											2.99*		
											1.86*		
											1.61*		
A16	PROD	****	****	****	****	****	****	****	****	****	1.96	4.98	3.59
	CHLA	****	****	****	****	****	****	****	****	****	1.15	****	7.07
	ASMA	****	****	****	****	****	****	****	****	****	1.70	****	0.51
											3.50*		
											8.51*		
											0.41*		

*SPECIAL REPORT DATED OCTOBER 12, 1977

VALUES OF **** REPRESENT DATA NOT AVAILABLE

TABLE 2. (CON'T)

1977 PRODUCTIVITY, CHLOROPHYLL A, AND ASSIMILATION RATIO A (CON'T)

		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
A17	PROD	****	****	****	****	****	****	****	****	****	2.03	3.23	2.49
	CHLA	****	****	****	****	****	****	****	****	****	2.68	1.37	1.88
	ASMA	****	****	****	****	****	****	****	****	****	0.76	2.36	1.32
											1.14*		
											2.00*		
											0.57*		
B8	PROD	****	****	****	****	****	****	****	****	****	1.71	3.36	3.18
	CHLA	****	****	****	****	****	****	****	****	****	1.36	1.31	1.82
	ASMA	****	****	****	****	****	****	****	****	****	1.26	2.56	1.75
											2.61*		
											1.46*		
											1.79*		
C1	PROD	0.86	2.12	3.77	6.56	5.01	5.84	25.66	32.30	0.57	2.58	1.25	0.37
	CHLA	0.93	1.03	1.04	5.07	1.39	1.47	5.67	2.72	1.29	2.54	0.92	6.76
	ASMA	0.92	2.06	3.63	1.29	3.60	3.97	4.53	11.88	0.44	1.02	1.36	0.05
											4.49*		
											3.47*		
											1.29*		
C2	PROD	1.54	2.57	4.16	7.19	6.76	12.68	24.20	29.76	0.50	****	****	****
	CHLA	0.20	0.97	1.33	3.13	1.62	2.67	3.81	3.16	1.56	****	****	****
	ASMA	7.70	2.65	3.13	2.30	4.17	4.75	6.35	9.42	0.32	****	****	****
C3	PROD	0.91	2.40	3.26	3.13	6.75	14.84	22.49	32.10	0.94	****	****	****
	CHLA	0.11	0.46	1.01	1.23	1.41	4.27	3.87	4.07	2.17	****	****	****
	ASMA	8.27	5.22	3.23	2.54	4.79	3.48	5.81	7.89	0.43	****	****	****

*SPECIAL REPORT DATED OCTOBER 12, 1977

VALUES OF **** REPRESENT DATA NOT AVAILABLE

TABLE 3.

1978 PRODUCTIVITY, CHLOROPHYLL A, AND ASSIMILATION RATIO A

		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC.
A1	PROD	1.05	3.21	*****	0.94	0.70	2.56	2.51	0.59	2.99	4.72	5.27	13.03
	CHLA	1.04	1.49	*****	0.53	0.65	2.88	2.76	0.48	0.73	2.04	1.09	2.53
	ASMA	1.01	2.15	*****	1.77	1.08	0.89	0.91	1.23	4.10	2.31	4.83	5.15
A2	PROD	1.98	3.26	0.68	6.15	6.51	10.10	6.16	2.98	20.09	9.20	7.20	5.73
	CHLA	1.16	2.16	1.29	2.36	3.37	3.75	4.04	2.14	6.46	4.06	3.55	1.19
	ASMA	1.71	1.51	0.53	2.61	1.93	2.69	1.53	1.39	3.11	2.27	2.03	4.82
A3	PROD	3.84	5.42	2.81	3.08	7.12	7.72	9.11	5.94	9.93	11.06	5.73	12.85
	CHLA	1.69	3.24	2.68	0.96	3.79	4.77	8.45	2.18	2.77	4.38	3.12	1.47
	ASMA	2.27	1.67	1.05	3.21	1.88	1.62	1.08	2.73	3.59	2.53	1.84	8.74
A4	PROD	3.06	6.03	4.20	11.42	7.98	13.08	10.14	4.47	8.67	12.81	19.26	8.39
	CHLA	1.20	2.00	3.72	2.86	4.14	5.37	8.21	3.38	2.53	2.93	13.62	1.24
	ASMA	2.55	3.02	1.13	3.99	1.93	2.44	1.24	1.32	3.30	4.37	1.41	6.77
A7	PROD	2.13	8.91	3.73	3.72	8.89	13.75	2.83	0.39	14.09	10.16	37.67	16.97
	CHLA	1.21	1.92	2.32	1.09	4.06	5.21	5.76	4.15	3.65	3.78	5.79	2.27
	ASMA	1.76	4.64	1.61	3.41	2.19	2.64	0.49	0.09	3.86	2.70	6.51	7.48
A8	PROD	0.85	1.66	1.06	1.39	1.65	3.81	2.72	5.23	6.24	6.24	17.82	4.69
	CHLA	1.03	1.43	1.18	1.76	2.39	5.86	4.70	3.73	4.06	5.12	4.05	1.04
	ASMA	0.83	1.16	0.90	0.79	0.69	0.65	0.58	1.40	1.54	1.22	4.40	4.51
A9	PROD	1.40	1.11	2.06	1.70	3.62	1.88	2.36	2.83	7.85	5.33	26.01	7.67
	CHLA	1.03	0.78	2.53	1.44	2.72	2.54	2.42	3.01	3.79	2.91	8.27	1.19
	ASMA	1.36	1.42	0.81	1.18	1.33	0.74	0.98	0.94	2.07	1.83	3.15	6.45
A11	PROD	*****	8.07	*****	4.31	2.79	8.68	*****	5.59	11.78	21.84	67.75	6.83
	CHLA	*****	1.60	*****	1.67	1.61	8.46	*****	9.01	2.40	2.90	13.26	1.53
	ASMA	*****	5.04	*****	2.58	1.73	1.03	*****	0.62	4.91	7.54	5.11	4.46

VALUE OF *****REPRESENT DATA NOT AVAILABLE

TABLE 3. (CON'T)

1978 PRODUCTIVITY, CHLOROPHYLL A, AND ASSIMILATION RATIO A (CON'T)

		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
A12	PROD	1.31	2.24	6.15	4.30	3.43	9.10	7.17	2.13	21.58	4.83	61.56	19.23
	CHLA	1.08	1.75	3.02	1.69	1.74	2.40	5.51	1.59	5.13	2.82	16.43	2.48
	ASMA	1.21	1.28	2.04	2.54	1.97	3.79	1.30	1.34	4.21	1.71	3.75	7.75
A13	PROD	1.65	2.29	1.79	1.58	1.49	3.59	0.94	1.51	19.48	4.09	5.42	13.17
	CHLA	0.84	1.98	3.64	1.52	1.23	2.60	3.64	1.45	7.34	2.50	2.00	2.00
	ASMA	1.96	1.16	0.49	1.04	1.21	1.38	0.26	1.04	2.65	1.64	2.71	6.59
A14	PROD	1.40	3.72	5.23	1.97	2.03	8.19	6.66	2.23	23.54	6.86	15.79	13.78
	CHLA	0.90	2.25	2.47	1.57	0.89	2.86	5.70	1.54	4.17	2.88	2.32	2.05
	ASMA	1.56	1.65	2.12	1.25	2.28	2.86	0.17	1.45	5.65	2.38	6.81	6.72
A15	PROD	3.67	6.33	7.12	3.46	4.80	6.34	2.65	2.47	17.00	6.11	37.89	21.27
	CHLA	1.78	2.09	3.79	0.95	3.42	5.05	3.36	1.64	2.87	6.07	7.39	1.53
	ASMA	2.06	3.03	1.88	3.64	1.40	1.26	0.79	1.51	5.92	1.01	5.13	13.90
A16	PROD	2.14	6.98	6.22	3.20	4.30	5.67	2.54	0.97	10.10	11.21	5.99	14.72
	CHLA	0.82	1.98	3.76	1.32	3.26	3.27	4.34	2.99	2.90	3.48	4.28	1.65
	ASMA	2.61	3.53	1.65	2.42	1.32	1.73	0.59	0.32	3.48	3.22	1.40	8.92
A17	PROD	2.31	5.65	2.53	2.06	1.05	3.80	3.01	0.33	21.58	7.86	6.82	14.32
	CHLA	1.70	3.21	1.49	3.40	1.61	3.11	4.88	1.91	5.13	2.49	1.34	1.79
	ASMA	1.36	1.76	1.70	0.61	0.65	1.22	0.62	0.17	4.21	3.16	5.09	8.00
B8	PROD	2.64	3.27	7.64	4.76	4.28	3.82	3.30	2.47	9.19	9.83	19.54	11.28
	CHLA	1.22	1.65	1.59	1.31	2.30	3.10	3.77	1.82	****	3.86	7.32	1.66
	ASMA	2.16	1.98	4.81	3.63	1.86	1.23	0.88	1.36	****	2.55	2.67	6.50
B9	PROD	****	3.76	5.52	5.71	3.87	1.12	5.32	1.66	34.66	6.48	28.51	11.82
	CHLA	****	2.12	3.72	****	2.07	4.05	3.95	1.74	11.83	3.95	6.08	2.34
	ASMA	****	1.77	1.48	****	1.87	0.28	1.35	0.95	2.93	1.64	4.69	5.05
C1	PROD	0.40	****	****	****	****	****	****	****	****	****	*****	***
	CHLA	0.38	****	****	****	****	****	****	****	****	****	*****	***
	ASMA	1.05	****	****	****	****	****	****	****	****	****	*****	***

VALUES OF **** REPRESENT DATA NOT AVAILABLE

CHANGES IN ZOOPLANKTON
IN OUTER LOS ANGELES-LONG BEACH HARBORS
1972 - 1978

INTRODUCTION

The zooplankton of Los Angeles-Long Beach Harbors is composed largely of calanoid copepods, cladocerans, chaetognaths, larvaceans, and the larvae of fishes and benthic invertebrates. *Acartia tonsa*, a calanoid copepod, is the most abundant species. This copepod is a hardy animal, able to tolerate relatively high temperatures and low salinities (AHF, 1976; Jeffries, 1962).

Many zooplankters are generalist feeders, consuming flagellates, detritus, and bacteria. The percentage taken of each food source differs according to the assimilation rates and size-related filtering efficiencies of the zooplankters (Saunders, 1970; Brooks, 1970). The proportion of each species in the population as a whole may vary seasonally or spatially according to the food supply.

Enrichment by fish wastes or sewage favors two foods of zooplankton: phytoplankton and bacteria. Diatoms and dinoflagellates can increase markedly in areas of nutrient enrichment, supporting large populations of zooplankton (Marshall, 1947; Parsons *et al.*, 1977). In more turbid waters, heterotrophs in the water column may convert about 70% of the daily input of metabolizable carbon into particulate organic carbon (Sibert and Brown, 1975). Rod-shaped bacteria may be abundant on particulate organic matter (Ferguson and Rublee, 1976; Sullivan *et al.*, 1978). The zooplankton feeding on these foods may either remain in the open-water food chain or eventually settle out to become food for benthic invertebrates and demersal fishes.

In order to assess the effect on zooplankton of beginning secondary treatment at the Terminal Island Treatment Plant, the plant's operations and the inclusion of secondary treatment of cannery effluents, it is necessary to determine the characteristics of zooplankton populations in and outside the area of influence from a historical perspective. To accomplish this Harbors Environmental Projects data from 1972-1978 were used.

METHODS

Plankton data from stations A1, A3 and A7 (outside harbor; mid-outer harbor and area of TITP influence, respectively) were analyzed from January 1972 to the present. Stations are shown on Figure 1. Those species looked at in detail were the three dominant copepods, *Acartia tonsa*, *Paracalanus parvus*, and *Corycaeus anglicus* and the three dominant Cladocera, *Podon polyphemoides*, *Evadne nordmanni*, and *Penilia avirostris*. Also included

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in this study are the total zooplankton concentration and the diversity index (Shannon-Wiener) of copepods and cladocerans through the years of sampling. These dominant species, as well as the total zooplankton concentration and diversity index, are shown in Figures 2 through 13. Figures 2 through 4 and 6 through 8 show the concentrations (number/m^3) of copepods and cladocerans respectively, collected from January 1972 through September 1977 using surface horizontal tows. Figures 5 and 9 show the concentrations of the same species, using vertical tows from bottom to surface from October 1977 through December 1978. Total zooplankton concentration and the diversity index of copepods and cladocerans are shown from the same sampling dates and methods in Figures 10 through 12 and 13, respectively. While the horizontal and vertical plankton sampling do not yield similar concentrations (vertical tows showed higher concentrations than horizontal tows), as evidenced by studies comparing the tow techniques, similar zooplankton trends (zooplankton maxima) should be evident and relative differences between the stations should be similar.

RESULTS

Acartia tonsa

The dominant zooplankter, *Acartia tonsa*, generally comprises over half of the total zooplankton concentration. Through the years of sampling, this species generally shows a low summer concentration, with a depressed mid-winter period. Concentrations are usually high in late fall-early winter and in late winter-early spring. This was the typical pattern from 1972 to to early 1974, the only deviation being when A7 showed a peak in the summer of 1972. The winter of 1974-75 and 1975-76 showed some deviation from the former pattern by the absences of an early spring and late fall peak, respectively. There was also an absence of a late fall peak in 1976, but the late winter-early spring peak of 1977 had an unprecedented high concentration of about 18,600 *A. tonsa*/m^3 at stations A3 and A7, with a low concentration (about 500 *A. tonsa*/m^3) for A1. The months of this exceptional concentration of *A. tonsa* (March-April) peaked at about the time that the Terminal Island Treatment Plant (TITP) converted to secondary treatment in April. The bloom probably was underway before conversion. It followed an unusually warm, dry winter that had some two inches of rain in late March. The extraordinary bloom of this single species made the zooplankton nearly axenic as evidenced by the unprecedented low diversity among copepods and cladocerans for a single month at stations A3 and A7, nearest the outfalls.

As diversity is advantageous for the stability of an ecosystem, anything which would cause the diversity to decline would be disadvantageous. Thus the initiation of secondary treatment may have been detrimental to the zooplankton ecology at that time;

however, the *A. tonsa* concentration returned to near normal concentrations by summer 1977, as did the diversity index. By September, TITP started processing the effluent from one cannery and by January 1978 all cannery effluent had entered TITP. It is this winter of 1977-78 that, for the first time since 1972, neither late fall nor early spring *A. tonsa* maxima were evident, which might be linked to the lack of effluent being discharged from the canneries. An *A. tonsa* peak, however, recurred in the fall of 1978 at station A1 outside the harbor and at A3 in mid-outer harbor, but not A7, near the treatment plant outfall, a station which had participated in the winter-time peaks in all pre-secondary treatment years.

It is interesting to consider the mean concentrations of *A. tonsa* at the above three stations during pre- and post- cannery effluent treatment. These data, as well as other copepod cladoceran species data, along with total zooplankton and diversity indices of copepods and cladocerans, are shown in Text Table 1. It can be seen that prior to cannery effluent treatment, the mean *A. tonsa* concentration was greatest at A7 and A3, with only about half those concentrations at A1. Following the cannery treatment, the mean *A. tonsa* concentrations indicate that the highest concentrations occurred at A3 and A1 -- over three times greater than at A7. This depressed concentration at A7 may be the result of secondary treatment processing; however, it must be remembered that the post-cannery treatment mean is based on fewer samples, and on samples which were collected by vertical tows, so that they are not directly comparable.

Text Table 1. Pre- and Post-Cannery Treatment
Zooplankton Concentrations

	A.tonsa	*P.parvus*	*C. anglicus*	*P.polyphemoides*	*E.nordmanni*	*P.avirostris*	Total Zooplank.	Species Diversity
Pre-Cannery Treatment (January 1972-September 1977)								
A1	577	598	93	403	943	16	3600	1.26
A3	1037	230	56	382	412	62	2528	1.07
A7	1133	150	36	452	286	7.8	2454	0.99
Post-Cannery Treatment (October 1977-December 1978)								
A1	1155	788	335	41	216	946	5514	1.56
A3	1398	578	101	41	58	394	3357	1.17
A7	370	202	38	60	14	36	1377	1.29

Paracalanus parvus and *Corycaeus anglicus*

The next two most abundant copepod species are the calanoid, *Paracalanus parvus*, and the cyclopoid, *Corycaeus anglicus*, which make up 10% and about 1.6% of the Los Angeles-Long Beach Harbor zooplankton, respectively (AHF, 1976). The concentrations of these species at stations A1, A3, and A7 over time are shown in Figures 2 through 5. There seems to be no clear seasonal trend for either of these species. The only major bloom of *P. parvus* at stations A3 and A7 occurred in the winter, 1972-73. Other than that peak, *P. parvus* showed peaks at station A7 greater than 500/m^3 only immediately after TITP converted to secondary treatment (April and May, 1977). Whether the lack of sewage and cannery effluent contributed to these peaks is unknown, since the overall ratio of A1 to A7 *P. parvus* concentrations (Text Table 1) remains unchanged from pre- to post-cannery treatment. *P. parvus* has been shown to be the most ubiquitous species (AHF, 1976) and thus may be the species least affected by perturbations in the environment.

Corycaeus anglicus is another species which showed only one major bloom during the seven years of sampling. This occurred in the spring of 1974. This species did not seen to show any stimulatory or inhibitory effect by the initiation of secondary treatment for sewage or cannery effluent, although the effect on total populations cannot be predicted for the long term.

Cladocerans

Cladocerans form the next most dominant group behind copepods. *Podon polyphemoides* and *Evadne nordmanni* are the two dominant cladoceran species comprising 11.1 and 4.7 percent of the zooplankton, respectively (AHF, 1976), with *Penilia avirostris* a distant third of minor importance. The changes in concentrations of the species over the seven years of sampling is shown in Figures 6 through 9.

Podon polyphemoides

Podon polyphemoides is a species that had two major blooms during the seven years of sampling. Those occurred in the spring of 1972 and 1976. Another bloom may have been in the making in the spring of 1977, as evidenced by the substantial increase of *P. polyphemoides* at A7. This bloom may have been cut short by the conversion of TITP to secondary treatment, since never before had there been such an intense increase without its lasting more than one month.

Following the first cannery effluent entering into TITP in September 1977, all three stations showed extremely low abundance of *P. polyphemoides*. After the last cannery was connected to the TITP (January 1978), there was a total absence of this species in the water column up to June 1978. Such an absence occurred one other time, in the spring of 1975, but for a much shorter period of time. Since *P. polyphemoides* was absent from all stations rather than just A7, it would tend to suggest that the absence might not have been a result of cannery effluent treatment. It should be noted, however, that this absence was broken with the return of *P. polyphemoides* to the water column following the malfunction of TITP in June. After September, when TITP was operating again, this species persisted in the water column through December. Text Table 1 shows the drastic drop in *P. polyphemoides* concentration after TITP processing of cannery effluent began. It also indicates that this species was evenly distributed and was not more or less abundant at any one station, either before or after TITP cannery effluent treatment.

Evadne nordmanni

Evadne nordmanni showed major blooms timed similarly to those of *P. polyphemoides*, both in the spring of 1972 and 1976. *Evadne nordmanni* shows no consistent seasonal trend, and as in the former cladoceran species, it, too, showed sparse populations present at all stations following the secondary treatment of cannery effluent. This low population level continued at all stations until October 1978, when A1, outside the harbor, showed a small bloom. Text Table 1 shows that *E. nordmanni* also experienced a decline in concentration as well as a change in numbers collected at station A7 as compared to A1. Prior to secondary treatment of cannery effluent, the A1 to A7 ratio was 3:1, while after treatment the ratio was 15:1. While the values may not be significant because of the fewer samples after treatment, it may indicate a trend toward greater sparsity of this species at the station (A7) most impacted by the secondary treatment of cannery effluent.

Penilia avirostris

This relatively minor member of the zooplankton is absent most of the time; however, when it is present, it is often very abundant. The only real abundance in the past six years prior to effluent treatment occurred in the fall of 1976. After treatment, however, a tremendous bloom occurred in the fall of both 1977 and 1978. These blooms were restricted primarily to A1 and A3, and thus may not be related to the cannery effluent treatment which might be manifested primarily at station A7, as compared with A1 and A3.

Total Zooplankton and Diversity Index

The concentration of total zooplankton and the Shannon-Wiener Diversity Index for copepods and cladocerans collected over the seven years of sampling stations A1, A3 and A7 are shown in Figures 10 through 13. The seasonal characteristics of total zooplankton are primarily functions of the already discussed dominant species of copepods and cladocerans. Text Table 1 shows, as would be expected from the previous discussion, that there was a reduced concentration of total zooplankton at A7 as compared to A1, after secondary treatment of cannery effluent was initiated. Prior to treatment, the A1:A7 ratio was 1.5:1, while after effluent treatment the ratio changed to 4:1.

Species diversities of copepods and cladocerans show considerable variability between stations and over time; generally they are higher at A1 outside the harbor than inside, and at station A1 there appears to be greater species diversity during the winter months than during the summer months. One period of very low diversity was observed at A3 and A7 in April 1977 with a bloom of *Acartia tonsa*, during the period when secondary sewage treatment was initiated.

Text Table 1 indicates a decline in diversity from outside the harbor (A1) to inside (A7) before cannery effluent treatment, as might be expected. After treatment, however, while A1 still had the greatest diversity, station A7 seemed to have been improved as compared to A3, since A3 then had the lower diversity. This may indicate that cannery effluent treatment may have improved the environment at A7, but it would perhaps have decreased the food available at A3, although the results are not conclusive.

Distribution of Total Zooplankton

Mean concentrations of zooplankton in 1973-74, shown in Figure 14 (AHF, 1976), indicate that outer Los Angeles Harbor was not an area of high concentrations; however, the same area was indicated as one of high fish concentrations in 1972-74, and predation may well have been the controlling factor except, perhaps, at those stations within the shallow water area closest to the outfalls (A4, A7, A11). Fish trawls were not taken in the shallow water area.

In spite of the increase in populations in 1978 at several perimeter stations (A2, A11, B8, B9), the mean total concentrations decreased at A7 (Figure 15). The 1978 data for other areas of the harbors have not been analyzed as yet, so it is not known whether changes have occurred in the B, C and D stations as well.

CONCLUSIONS

The milestone events during conversion of waste treatment from primary to secondary and inclusion of cannery wastes in TITP can coincidentally be seen in variations in numbers of the dominant zooplankton in the harbor as compared with a station outside the harbor. Although the variations cannot be proven to be due to the changes, the coincidences are notable.

The copepods probably feed largely, and perhaps preferentially, on bacteria on organic detritus; therefore the more than thirty-fold decrease in total marine bacteria plus a four- to seven-fold decrease in phytoplankton assimilation would have had an effect. Copepods apparently are able to select enriched particles from unenriched particles of the same size (Poulet and Marsot, 1978).

The fact that total concentrations are not greatly increased might be related to the large drop in fish predators discussed elsewhere, leaving about the same standing crop even if the gross production was much reduced. Replenishment by tidal exchange is also important, but is largely unquantifiable. Changes in the method of collection between 1974 and 1978 preclude direct comparison of total zooplankton.

The so-called "zone of inhibition" previously identified (Soule and Oguri, 1976) near station A7 was an area of very high nutrient levels, but the turnover of the nutrients was postulated as contributing to the "zone of enhancement" that included most of the outer harbor. The perimeter of the "zone of enhancement" may now have moved much closer to A7, resulting in improved diversity there and larger populations in the outermost stations of the area (A2, B8, B9). However, both A7 and A1 decreased substantially in total populations. Since no further monitoring is planned after December 1978 by the City of Los Angeles, it will not be possible to say whether the apparent changes represent long-term trends.

LITERATURE CITED: See Section Vi.

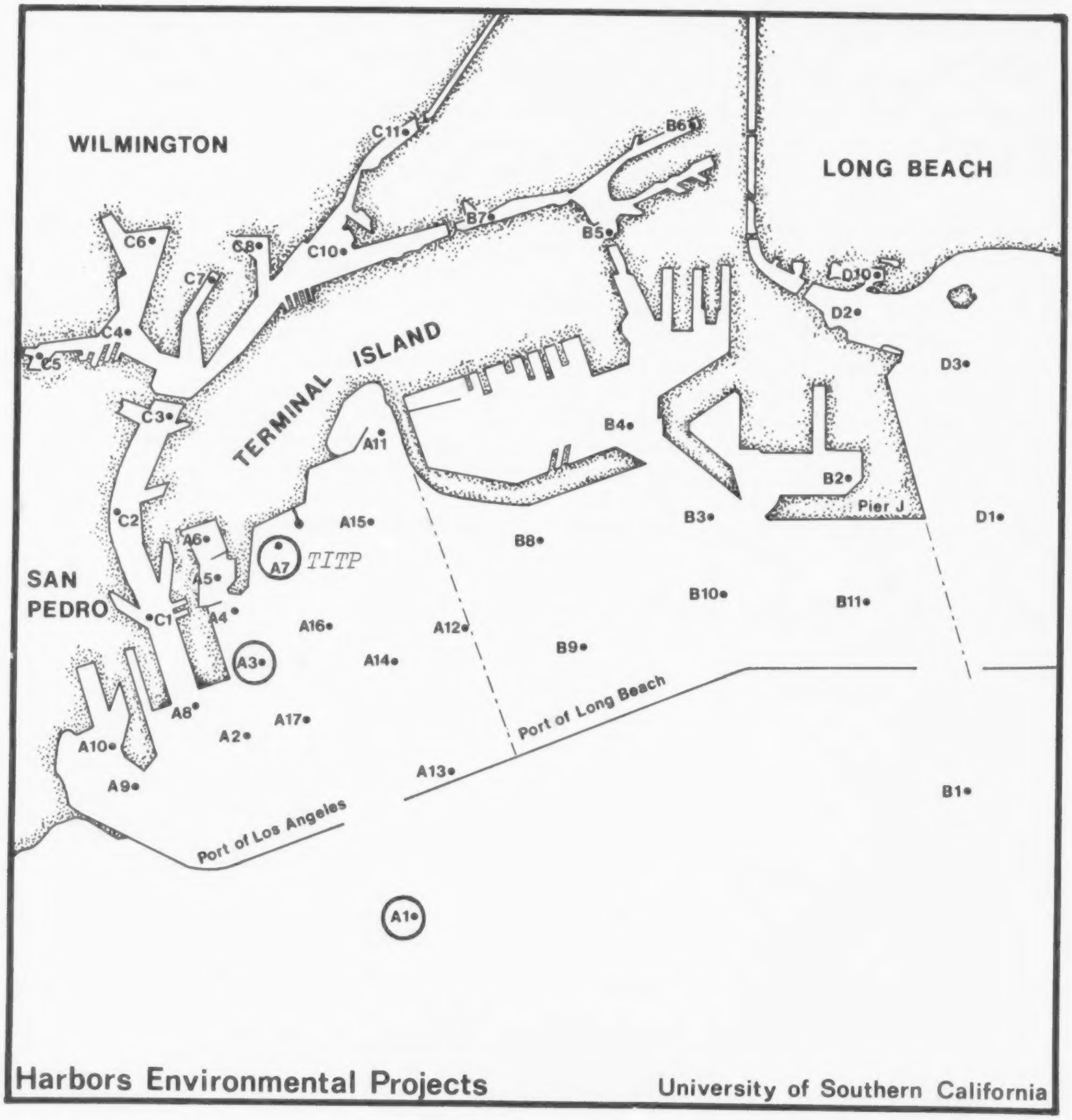

Figure 1. Zooplankton Analysis of Selected Stations

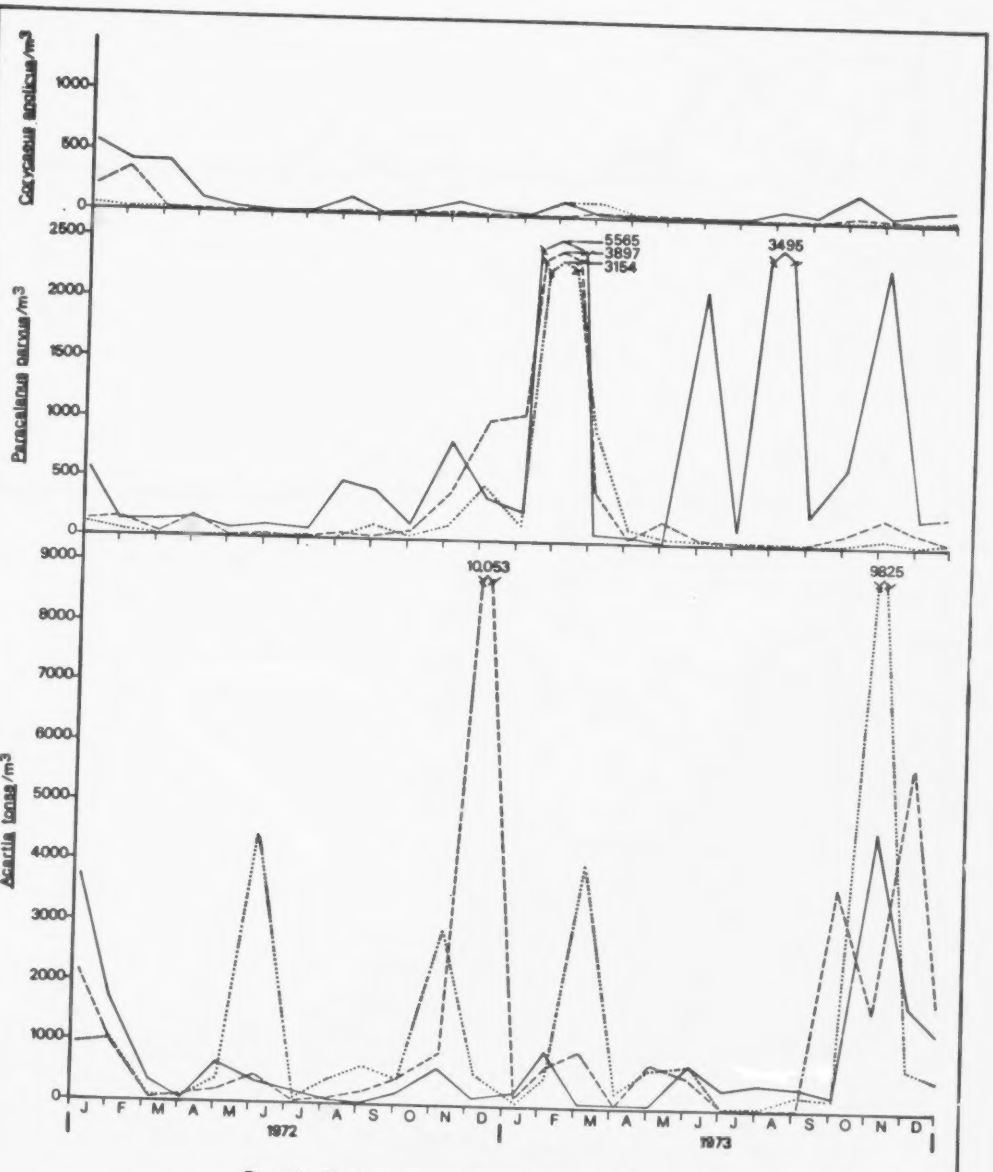

Figure 2 Dominant copepod concentrations, Jan. 1972 - Dec. 1973
Station A1 ———, A3 – – – –, A7 ··········

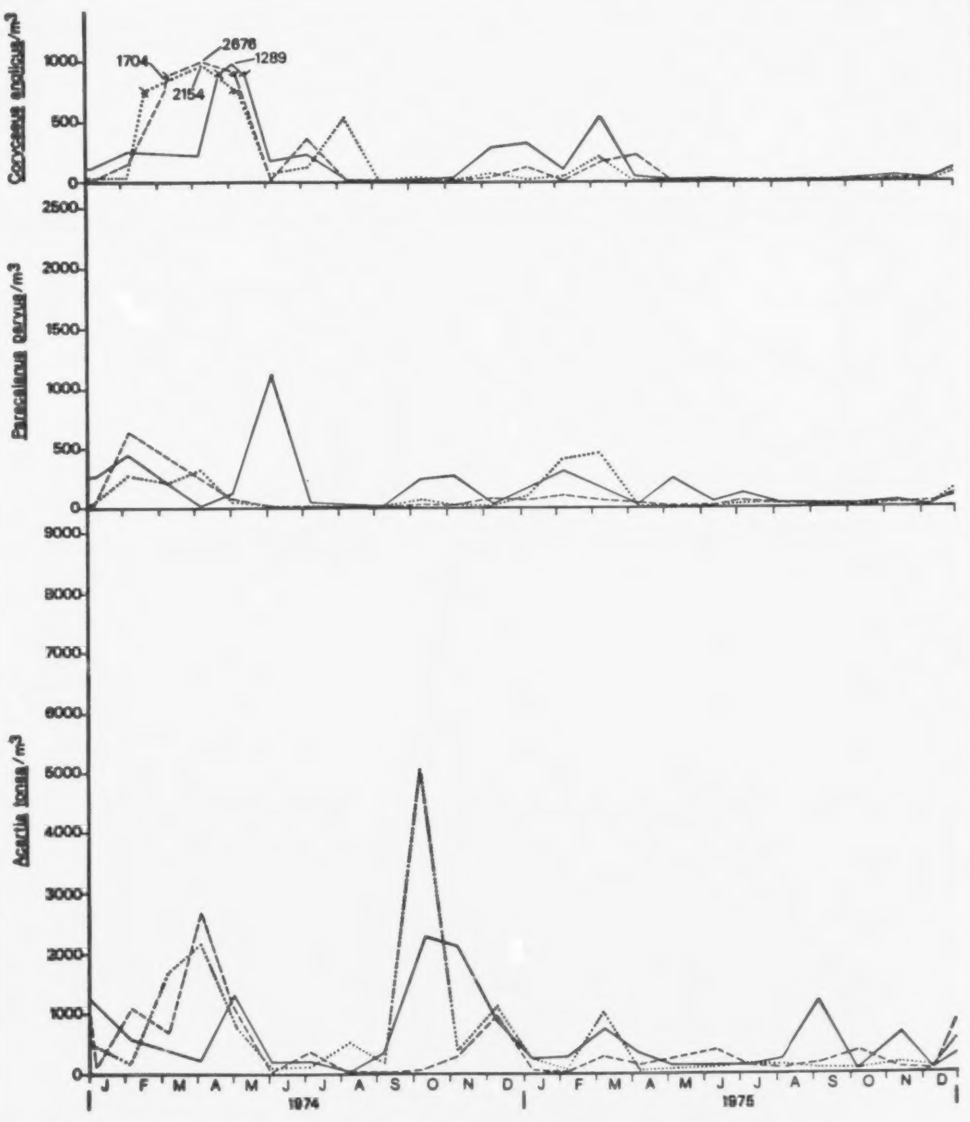

Figure 3. Dominant copepod concentrations, Jan 1974 · Dec. 1975
Station A1 ——— ,A3 – – – – ,A7 ·········

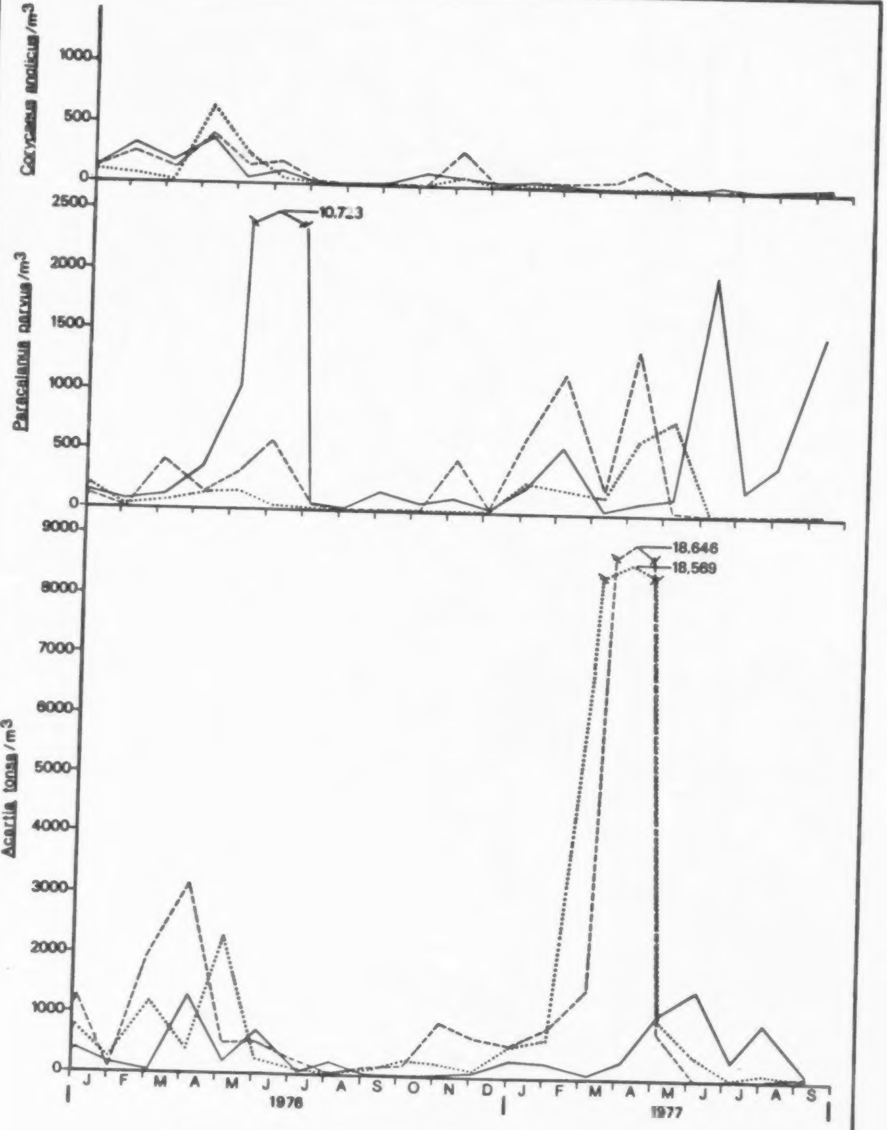

Figure 4 Dominant copepod concentrations, Jan. 1976 - Sept. 1977
Station A1 ——— ,A3 - - - - ,A7 ·········

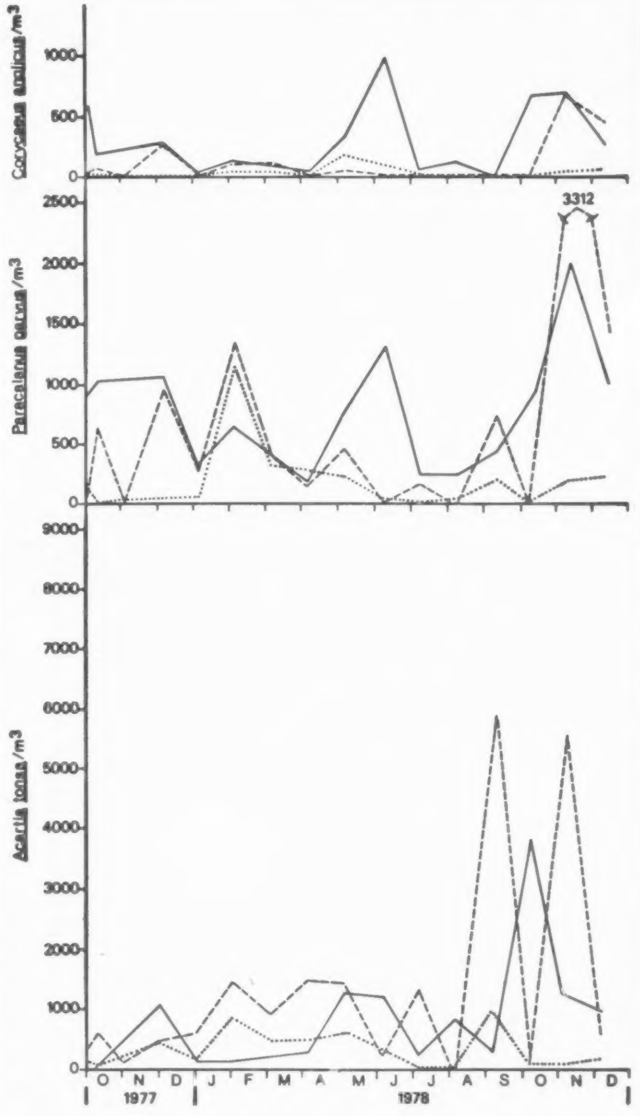

Figure 5. Dominant copepod concentrations, Oct. 1977 - Dec. 1978
Station A1 ——— ,A3 - - - - ,A7 ·······

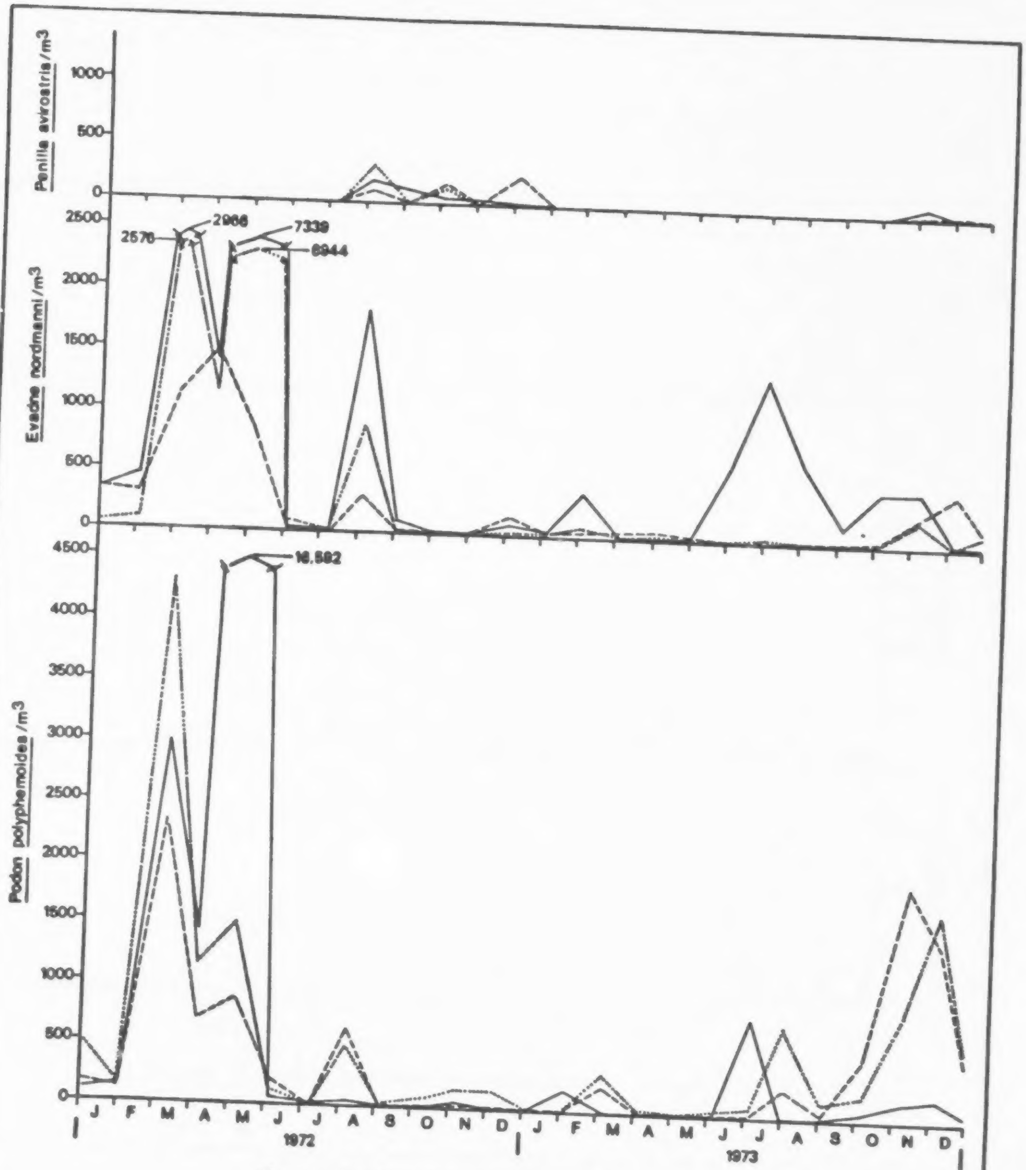

Figure 6. Dominant cladoceran concentrations, Jan. 1972 - Dec. 1973
Station A1——— ,A3——— ,A7———

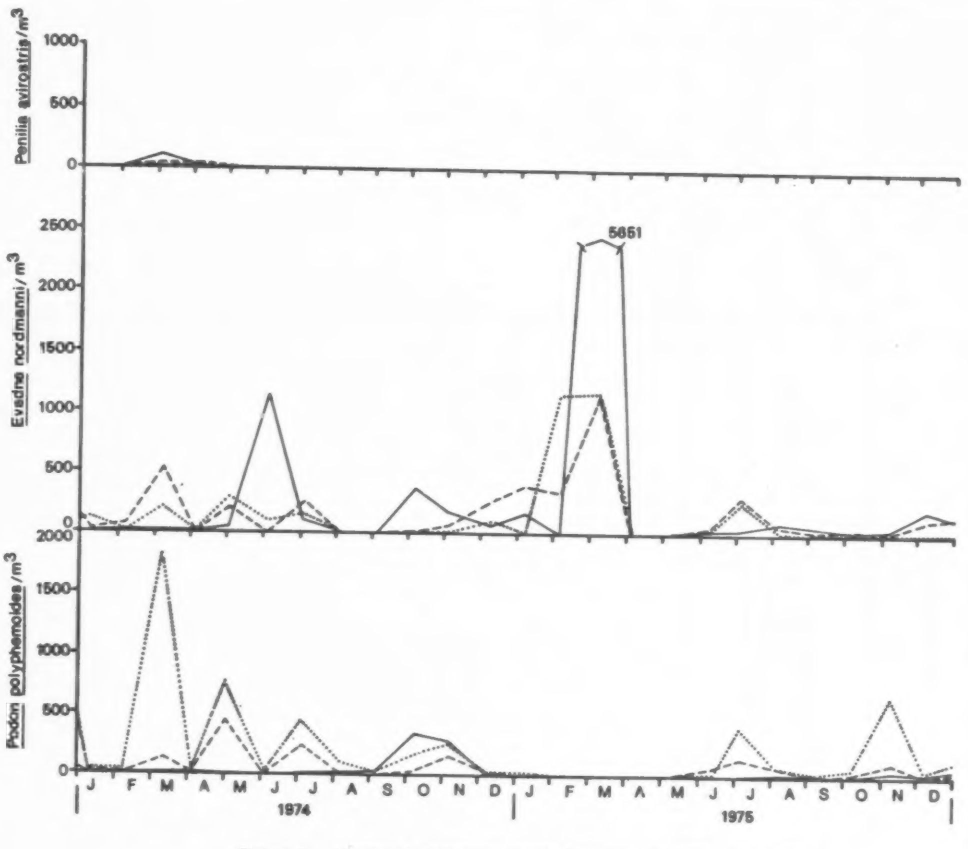

Figure 7. Dominant cladoceran concentrations, Jan. 1974 - Dec. 1975

Stations A1 ——, A3 ----, A7 ....

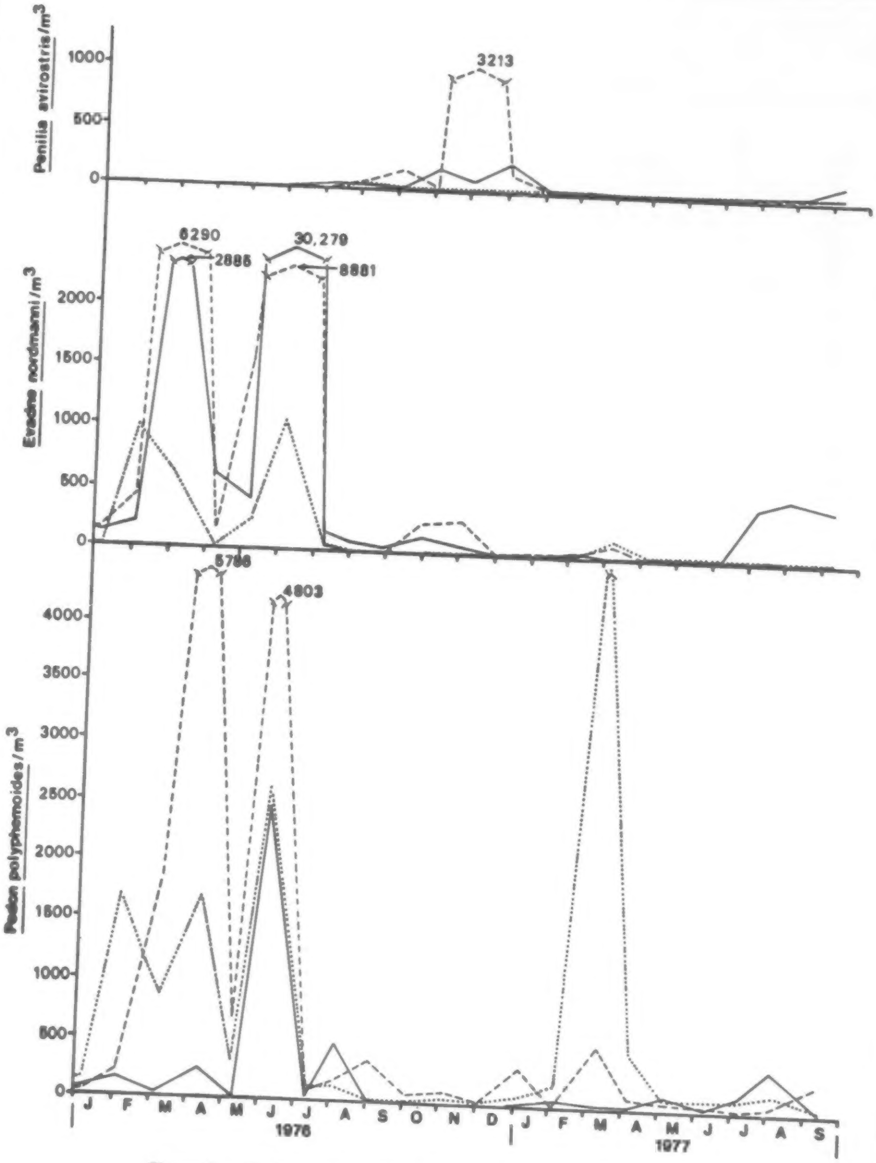

Figure 8. Dominant cladoceran concentrations, Jan. 1976 - Sep. 1977

Stations A1 ——, A3 ----, A7 ....

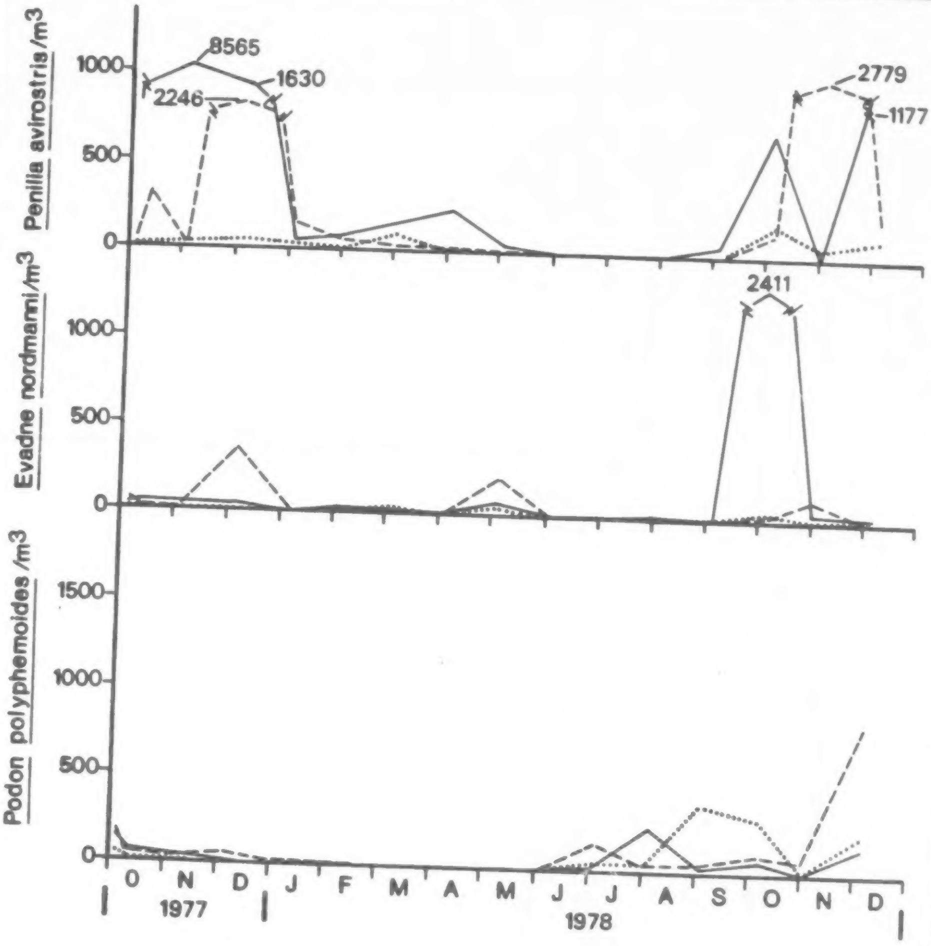

Figure 9. Dominant cladoceran concentrations, Oct. 1977 - Dec. 1978
Station A1——— ,A3 – – – – ,A7············

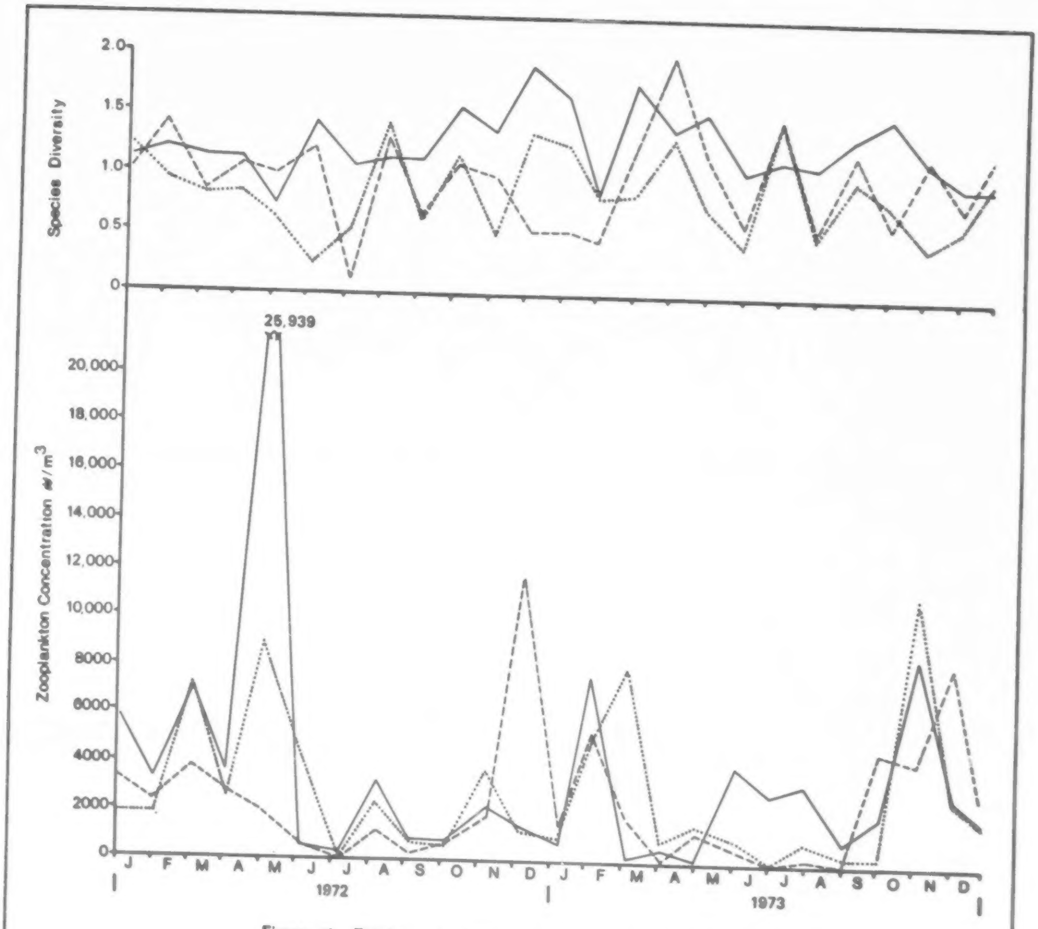

Figure 10. Total zooplankton conc. ; Copepod and cladoceran diversity
Jan. 1972 - Dec. 1973 Stations A1——, A3– – –, A7·······

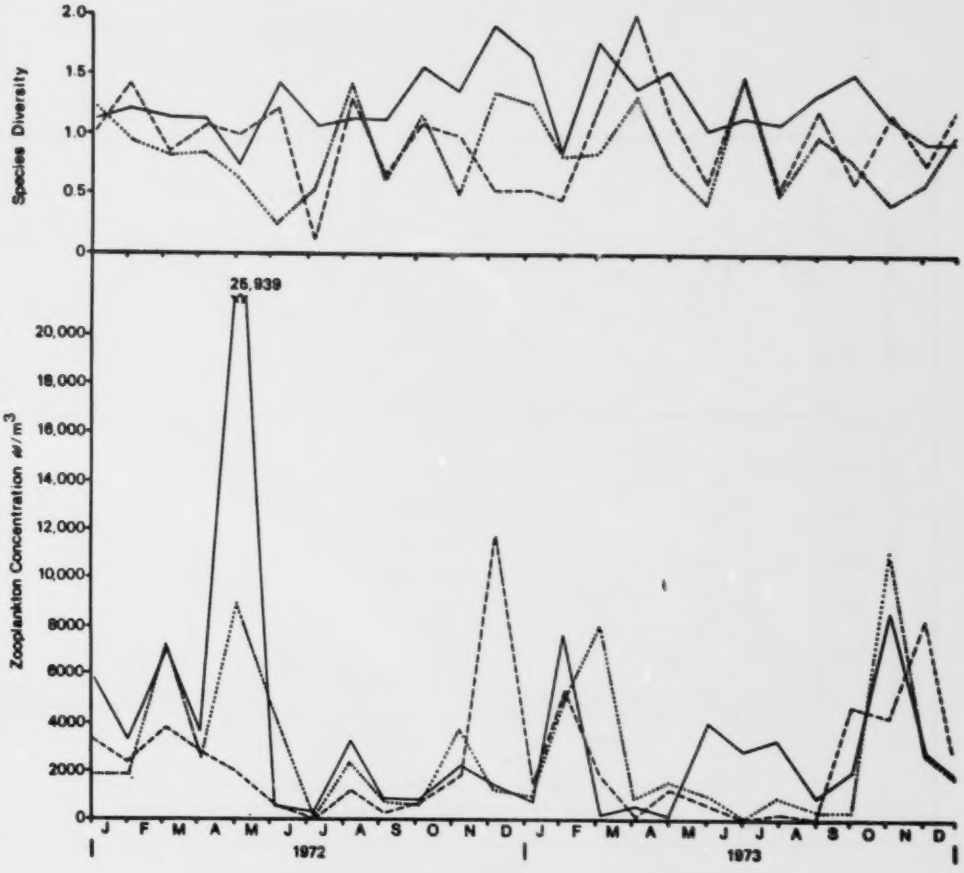

Figure 10. Total zooplankton conc. ; Copepod and cladoceran diversity
Jan. 1972 - Dec. 1973 Stations A1——, A3——, A7——

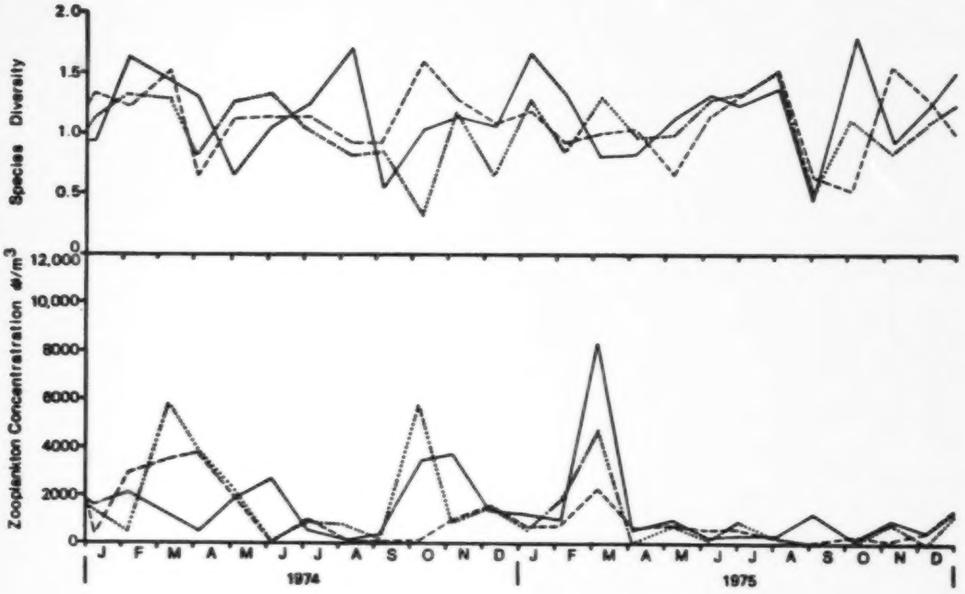

Figure 11. Total zooplankton conc. ; Copepod and cladoceran diversity Jan. 1974 - Dec. 1975 Stations A1——, A3----, A7------

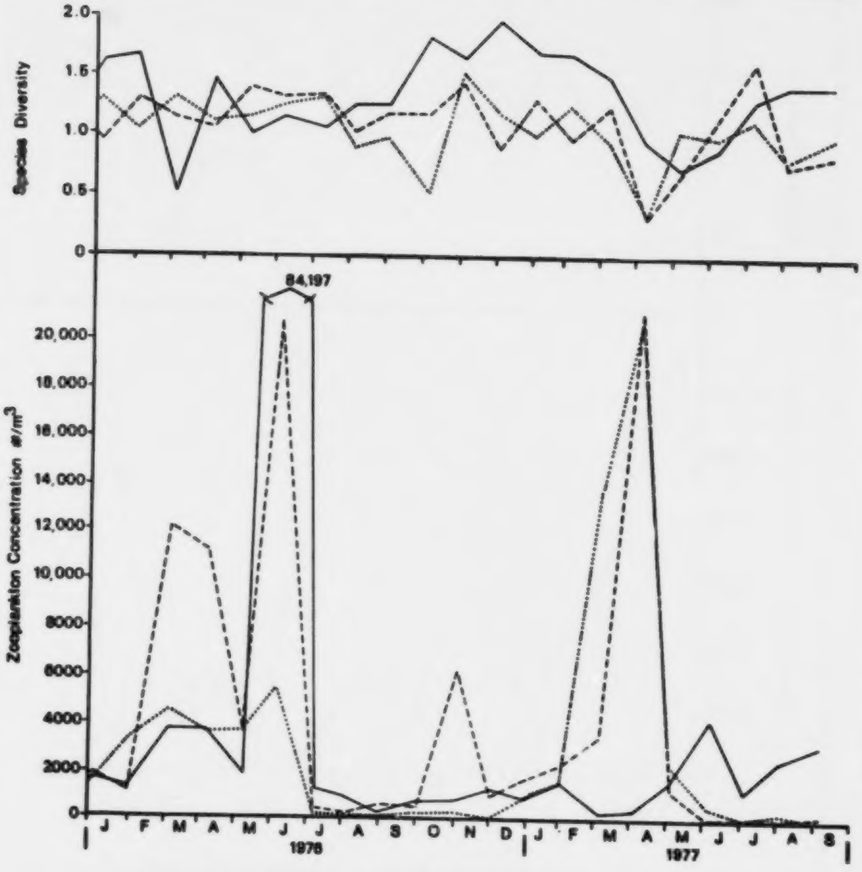

Figure 12. Total zooplankton conc. ; Copepod and cladoceran diversity
Jan. 1976 - Sep. 1977 Stations A1——, A3- - - -, A7·······

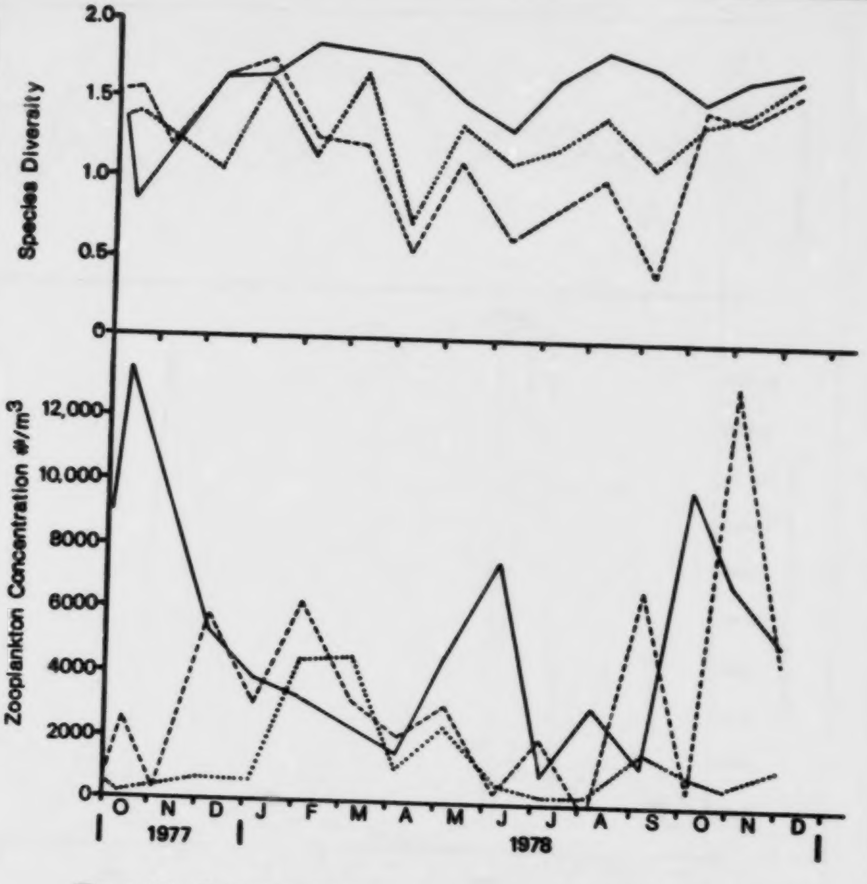

Figure 13. Total zooplankton conc. Copepod and cladoceran diversity
Oct. 1977 - Dec. 1978 Station A1———, A3-------, A7 ---------

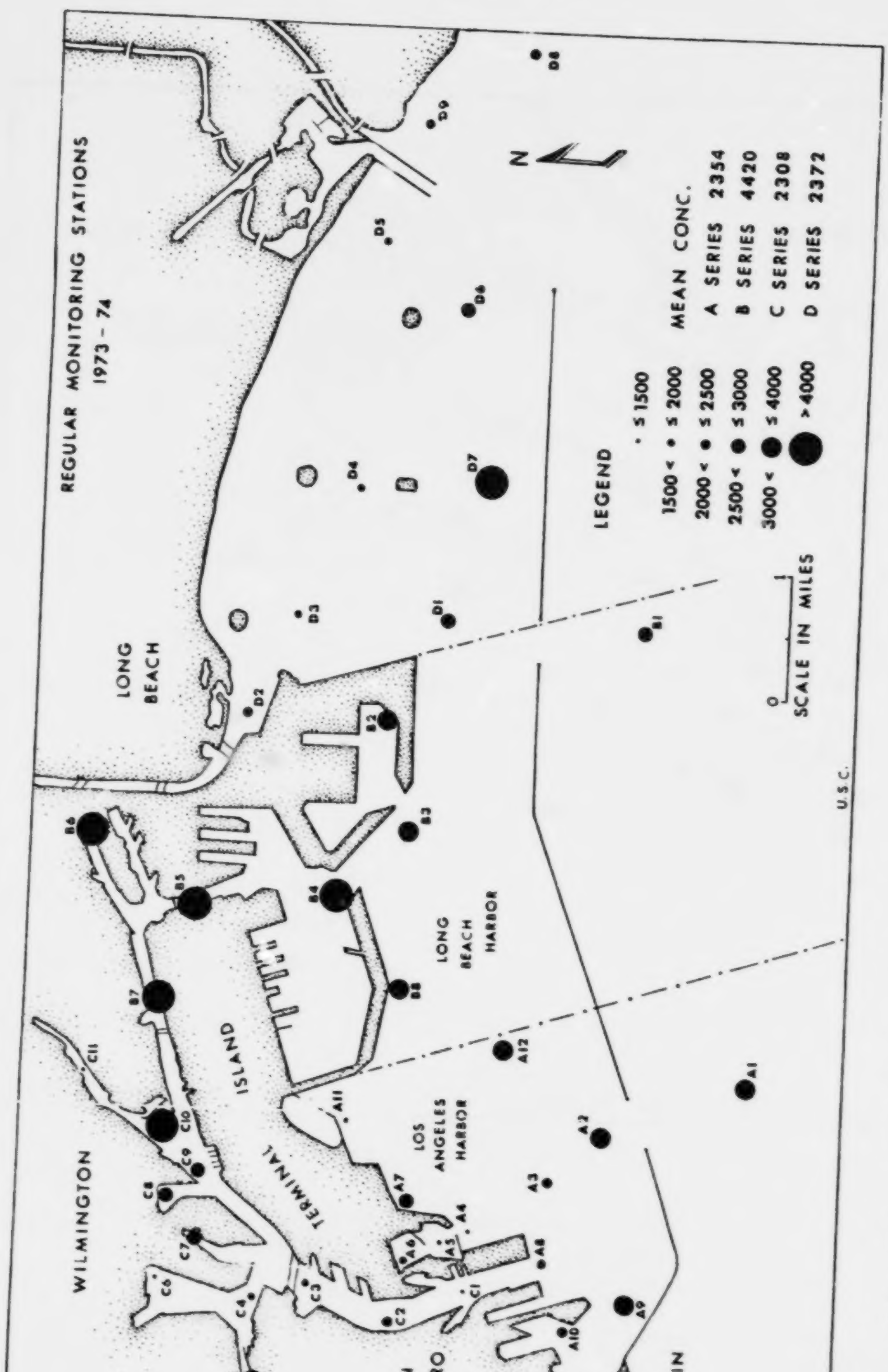

Figure 14. Mean Spatial Distribution of Total Zooplankton (Source: AHF, 1976)

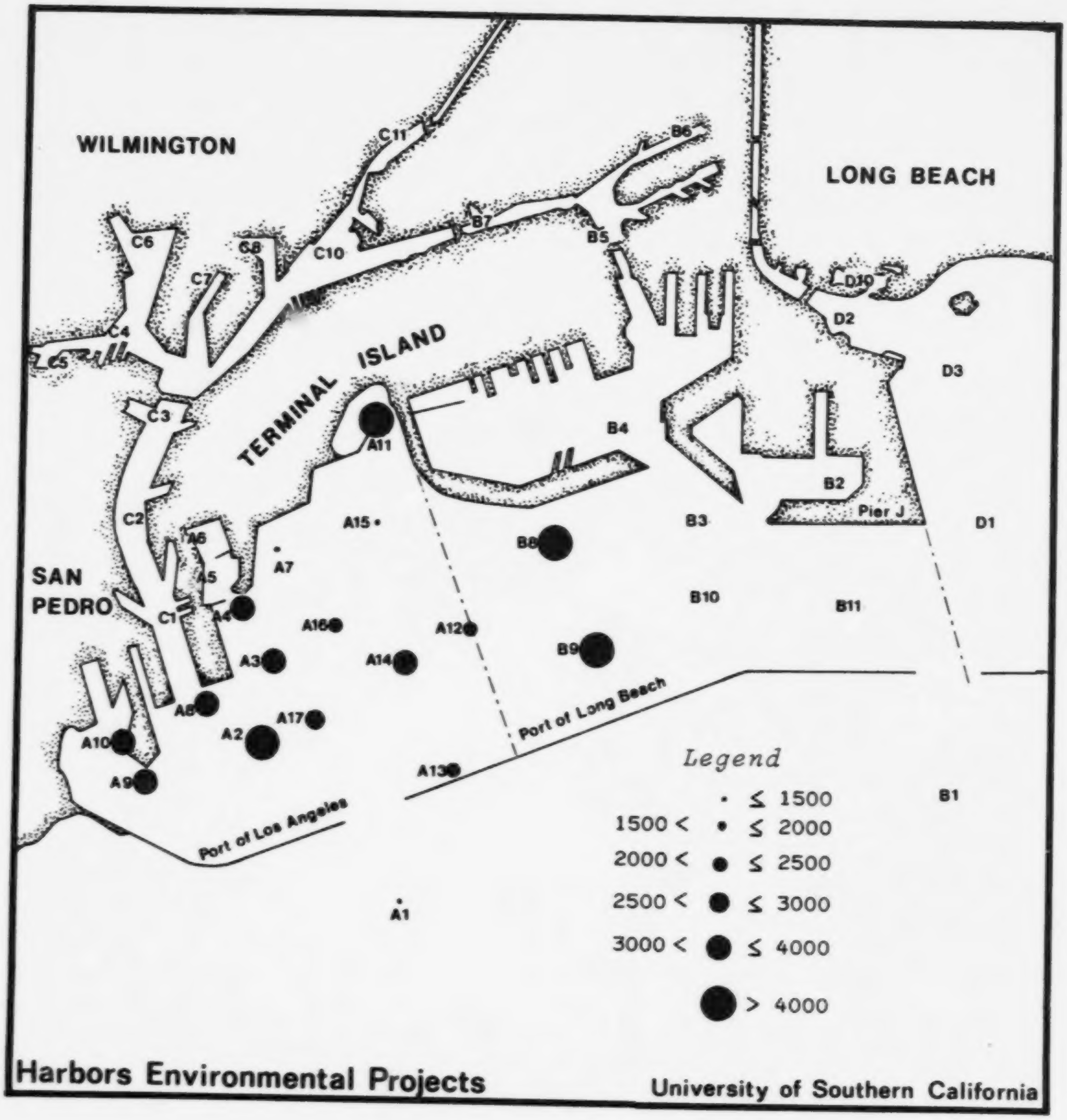

Figure 15. Mean Concentrations of Total Zooplankton in the Outer Harbor, 1978

CHANGES IN BENTHIC FAUNA IN OUTER LOS ANGELES-LONG BEACH HARBORS, 1972-1978

INTRODUCTION

Benthic organisms have been sampled extensively in the outfalls area of outer Los Angeles Harbor since 1971 by Harbors Environmental Projects, and results of studies through 1974 were published in part in 1976 (AHF, 1976).

In the 1973-74 period, 43 stations were sampled quarterly and results showed that for the entire harbor the average sample contained 28 benthic species and 1404 individuals per 1/16 m^2. The range of variation was high, with species numbers from 1 to 60 per sample, and abundances from 2 to 5000 per sample. The latter number becomes 80,000 organisms when calculated to the square meter of surface, an extremely rich benthos as compared with other local soft-bottom areas (Soule and Oguri, 1976; Word, Myers and Mearns, 1977). Other studies on biomass and simulated recolonization of dredged areas indicated that biomass averaged 20-30 gm/m^2 in the outer harbor near the breakwater, 200 gm/m^2 at stations nearest shore, and 500 gm/m^2 in the central portion out from the cannery and sewage outfalls area (the zone of enrichment) (Soule and Oguri, 1976a, b).

A quote from the Master Environmental Setting for the Port of Long Beach (1976) with regard to the importance of benthic populations and plans to dredge and fill the central enhanced area reads as follows:

> "The importance of benthic animals to the entire food web of the harbor is not well recognized. Polychaete worms are the largest number of harbor benthic organisms. They filter organic detritus and bacteria out of water, or consume them from sediments when feeding. Polychaetes, in turn, furnish a major food source for large harbor fish populations of a number of species. If both ports completed their Southwest Basin dredging and filling, an estimated 8.5×10^8 grams (850 tons) of organisms would be lost by burial; dredging would destroy an additional 6.8×10^8 grams (680 tons).
>
> "Since large polychaetes may weigh less than 0.1 gram, that represents 15.3 billion worms. In one fish stomach examined recently, 600 worms were found, so the direct consequences for those fish feeding on benthic polychaete worms can be estimated as 25 million 'fish meals.'"

The area of enhancement is dependent upon the existence of a large, slow-moving gyre in the outer harbor directly south of the outfalls area which apparently circles clockwise on the surface and counter-clockwise beneath (Soule and Oguri, 1972; Robinson and Porath, 1974). The surface gyre has been verified and simulated by the U.S. Army Engineers Waterways Experiment Station model at Vicksburg, Miss. (McAnally, 1975, 1976); it is figured in section IVA. The harbor gyre system facilitates distribution and assimilation of the organic nutrients, and contributes to oxygen levels by mixing, which accounts in large measure for the health of the harbor.

METHODS

The locations of the benthic stations sampled in the harbors are given in Figure 1, along with the stations sampled in prior years in various studies. The box on the map outlines the TITP study area; station A7 is near the outfalls location. Harbors Environmental Projects has published and unpublished records for stations A1-A8 beginning in 1971 with studies for Pacific Lighting Corporation's proposed LNG terminal.

Sediment samples were taken from the RV *Vantuna* in 1977-78 using a stainless steel Reinecke box corer. The corer is a modified spade corer which takes a sample with 1/16 m^2 of surface and up to 30 cm in depth. On board, two 100 cc subsamples for chemical analysis and for grain size analysis were taken from the middle surface of each core and frozen immediately for later laboratory techniques. The upper half of the core was then taken and washed with running sea water through a 0.5 mm screen. Material retained on the screen was fixed immediately in formalin-sea water and later transferred to isopropyl alcohol for sorting and identification. In locations too shallow for the *Vantuna* (at A7) the RV *Golden West* was used to operate a stainless steel Campbell grab sampler (similar to a Van Veen), which takes a 1/10 m^2 surface sample. Care was taken to obtain the chemical samples from the surface of the box core where it would not have been touched by metal. Since the surface sediment is undisturbed with the Reinecke corer, it is the preferred gear. In addition to the results discussed below in this section, section IV contains extensive discriminant computer analysis of benthic data.

Data gathered on the 1977-1978 benthic samples were compared with the data previously gathered, beginning in 1971. In addition, stations were compared concurrently according to locations (spatially) to seek indications of differences in the harbor environment and in seasonality.

RESULTS AND DISCUSSION

The baseline on benthic sampling beginning in 1971 first condensed to annual means at all stations sampled in each year, for both numbers of species/m^2 and numbers of individuals/m^2

(Figure 2). The means for each station have been calculated in Table 1 for all sample years (across the page) and for all stations in each year (vertically).

Annual Mean Trends in Diversity and Populations

In the benthic data plotted as annual means, there was very low species diversity (richness) and numbers of organisms per m^2 (abundance) in 1971. This no doubt reflects the comparatively poor harbor environment that existed prior to enforcement by the RWQCB of prohibitions on oil refinery and other toxic wastes in September 1970 (Reish, 1959; Crippen and Reish, 1969).

Reish (1971) documented the dramatic change in the inner Los Angeles Harbor as anoxic conditions began to disappear. Fish Harbor, in outer Los Angeles Harbor (stations A5 and A6) also was anoxic from dumping of fish wastes, process and non-process water; the wastes were diverted in 1970 to outfalls in the A7 area near TITP. The large increases, to 1972-74 levels, seen in both species diversity and abundance are probably due to the intensive enforcement effort, which allowed extensive new colonization to occur. Such an increase will usually be followed by a slight drop before stabilization of species and populations occur (Soule and Oguri, 1977) in normal succession. Thus, the principal trends in 1971-1973 were steep climbs in both numbers of species and numbers of individuals. The curve leveled off in 1974 for numbers of species but began to decline for numbers of individuals.

The principal trend since 1974 in the Los Angeles Harbor area has been a decline in total abundances (numbers of individuals) of benthic organisms. The trend in species diversity was upward through 1976, followed by a moderate decline in 1977 and a steep decline in 1978.

Site Specific Trends in Diversity and Populations

In order to examine the trends in different benthic locations, several stations were selected according to their distance from the TITP and cannery outfalls. Station A1 is located outside the harbor, whereas A2 is in the seaward area of the outer harbor, and station A3 is about halfway between A2 and A7. Station A7 is closest to the outfalls, being between the cannery outfalls on the west and TITP outfall to the east. Station A2 is located at one of the harbor Coast Guard buoys which was moved from A2a (Figure 1) to A2 in March 1973. Hence there was some difference in the substrate and species found in 1972 to 1973 data. This apparently did not affect other biological data since water column samples are not as static as benthic samples are.

The data for the specific sites mentioned are presented in Figures 3-6, on a seasonal (approximately quarterly) as well as an annual basis. Numbers of species and numbers of organisms per m^2 for each station are plotted and the trends discussed below.

Station A1. While station A1 is outside the Los Angeles Harbor entry (Angels Gate) and more subject to ocean conditions, it is still tidally influenced by the harbor. Terrigenous nutrients are carried by the natural flow of fine sediments down slopes to deeper waters at all river and bay entrances not blocked by sills or sand bars. The nutrients support the phytoplankton, algae, marine plants, microheterotrophic bacteria, and protistans on which benthic organisms feed. Thus the benthic zone of enhancement from the enriched harbor actually extends outside a short distance, especially for benthic organisms. The nutrient-poor (oligotrophic) character of most of the ocean waters may be encountered only past the Channel Islands in some cases, because of the terrestrial input of nutrients. It is because of terrestrial inputs that coastal inshore biota are the richest around the world. Even nutrients in upwelling areas were carried first from the coasts down into deep canyons before being recycled by upwelling. The years 1972, 1973 and 1974 were peak years for benthic organisms outside the harbor at A1 (Figure 3) as well as inside the harbor. Although all stations showed a precipitous drop in abundance beginning in mid-1974, it was least dramatic at A1 where benthic populations have always been smaller.

In the spring of 1976 and 1977 the expected late winter-early spring increases in numbers occurred but were of relatively small magnitude at A1. The slope of the abundance curve has been down, except for seasonal variations, since February 1975. The use of DAF treatment by the canneries began, coincidentally, in March 1975, reducing the nutrient load greatly.

Species diversity rose steeply over the long term, from 1971 through 1976, at A1, but with great seasonal fluctuations. Species diversity then dropped very steeply after December 1976 through 1978 and showed no sign of recovery other than seasonal fluctuation. Thus both species abundance and species diversity appear to have suffered a long-term decline at A1, in 1977 and 1978.

Station A2. The outer harbor station A2 (Figure 4) showed about four times as many organisms in August 1974 as A1 (Figure 3). Station A2 has shown about a tenfold decline in abundance overall between May of 1974 and the end of 1978, but there were larger intervening seasonal peaks than those at A1. An unusual summer peak in 1976 and 1977 occurred at stations A2 and A3 (Figures 4, 5) which did not occur at A1.

Station A3. The net slope of the curve for abundance at A3 is generally downward from a peak in 1972-73, but it was not as steep as that for A2. The species diversity seemed to be fairly stable at A2 and A3, although they show large seasonal fluctuations. Peaks in diversity occurred in the summer of 1976, 1977 and 1978 at A2, A3 and A7 but not at A1.

Station A7. At station A7 (Figure 6) during the summer, fall and winter of 1976, the abundances declined severely but recovered slightly in June 1977. Numbers dropped again in September 1977, recovered in the winter, dropped in April 1978, recovered in July, and dropped again in October 1978. Note the lower scales on the A7 graph. Station A7 was greatly influenced by the outfalls. When DAF units were unstable, or were using large quantities of alum in 1975-76, when TITP construction created unusual conditions, such events were reflected in the benthic populations. It is possible that drought conditions in the winter of 1975-1976 also affected the area by reducing flushing. Chlorination was in effect from March through August 1978 and may have had a deleterious effect (Oliver and Carey, 1977; Emerson, 1976). Also, about 30 inches of rain fell in the three months of 1978, which would affect plankton more than benthic organisms. The diversity peaks in the harbor were lower near the outfall at A7 in 1976 and 1977; however, in 1978 the peaks in both abundance and species diversity were comparatively higher than at A3.

The 1977 and 1978 variations are compared in Figure 8 for stations A1, A2, A3, A7 and A12 and in Figure 9 for A4, A8, A9 and A11. In Figure 8, the net trend shown was down in both number of species and number of organisms for A1, A2 and A12. All except A7 showed a sharp drop in April 1978.

At station A2 the net trend was down less sharply in number of species and more sharply in abundance; the species numbers at A2 appeared to be the only ones on the rise in October 1978 of the five stations.

At A3 the species down-trend paralleled that of A1, but the abundance trend was steeply upward, as was that of A7.

At A7 the species diversity net trend was upward but had turned downward in October 1978. The number of organisms is sharply up by the end of October 1978, but the oscillations were extreme in the 1977-78 period.

It is important to look at the beginning and end points for these trends. However, the events in waste treatment in the harbor can be tracked because benthic worms, in particular, reproduce year around and an area can be recolonized within as little as two weeks to a month. Thus, A7 and A2 appeared to increase in species numbers in June 1977 when TITP went on secondary, while A1 decreased in both species and numbers, due perhaps to fewer nutrients. All but A1 increased in numbers in June. In September, both species and population numbers dropped steeply at all four stations except A7, which had a slight increase in numbers. One cannery hooked up to TITP in October and the other in December 1977. The sharp drop in species and numbers continued through January and April 1978 instead of showing the usual late winter increase, except at A7, which showed a small increase in species and very large population increase. Stations A1 and A12 showed small expected January increases before the April lows.

In July 1978 all the stations in Figure 8 increased sharply in species except A7, whose peak was blunted. All the stations except A7 showed moderate (A1) to sharp increases in population during the period of TITP release of high BOD and suspended solids. In October, after stability of sorts returned, all stations showed a drop in species except A2, while populations were up at A3 and A7 (nearest TITP), but down at all other stations.

Data for the other stations in the area, including those in Figure 9, show a similar pattern; when canneries and/or TITP were enriching, it appeared that most of the outer harbor stations were enhanced and increased in diversity and populations. Stations A4, A8, and A11 showed net drops in numbers of species, while A9 was about even in spite of the impact of the *Sansinena* spill. In numbers, A4 decreased greatly, A8 was increased slightly and A11 had a net increase. All showed fluctuations but the September 1977-April 1978 period showed the widest shifts. When TITP is on full secondary treatment, it appears that A7, A11 and, at times, A2 will increase (become enhanced) and the other stations decrease dramatically. When canneries or primary TITP were on, A7, A11 and sometimes A3 retreated while the others increased.

The number of species at A7 would probably always be lower because of the freshwater effluent, sometimes chlorinated, from TITP and storm runoff. Station A9 (Figure 1) is of interest because it is across the main channel and in a different hydrographic gyre; it was also the site of the *Sansinena* tanker explosion and Bunker C spill, which was intensively studied by Harbors Environmental Projects (Soule and Oguri, 1978). Station A9 (Figure 7), which had been sampled a few days before the explosion, showed a steady drop in species and numbers from December 1976. By September 1977 species diversity had recovered greatly and populations recovered to a lesser extent. However, winter storms, high temperatures, and reconstruction of the pier released much buried tar into the water and drove the numbers sharply down through January to an unprecedented low in April of 1978. These events can clearly be marked in the benthic plot. By July 1978 counts and species had increased so that the net slope for abundances for seven years was negligible and the slope for species numbers was slightly up. The prominent peak in numbers occurred in the fall of 1973, while the highest peak in species occurred in the spring of 1976.

Qualitative Evaluation of Species Composition

At the representative stations selected for graphic comparison, notes were made on the most abundant species, as they were first noted in the AHF (1976) report. Species were recorded as abundant if they constituted a large percentage (usually 35% or more) of the total animals. Common species usually occurred in quantities of over 2,000/m^2.

Station A1

Seasonality. Throughout the 1972-1978 sampling, the populations of the most numerous species, *M. californiensis* and *Tharyx*, show wide fluctuations, with peak size in spring months and lows in the autumn. Other species tend to be more stable but still show this seasonality at station A1.

General Trends. A marked reduction in population size for all species began in October 1975 and continued to October 1978. Diversity appeared to increase from October 1975 through March 1977; however, this was probably a result of multiple grab sampling. For this period the counts of individuals were adjusted to per-grab averages but there was no way to deal with the increase of rarer species encountered. A prime example of this occurred in December 1976 when 13 grab samples yielded 97 taxa. In section IVB on multiple discriminant computer analysis only the Polychaeta and Mollusca are used to aid in correction of this factor.

Recently there has been some indication of faunistic change. Beginning January 1978 *Mediomastus californiensis* was no longer numerically important. The October 1978 sampling stands out, as both *Tharyx* and *M. californiensis* were virtually gone. These two had comprised 60% of the total harbor population in 1973. However, although ranking and species changed, the fauna was otherwise typical of the outer harbor area (Table 2).

Station A3

Seasonality. *Mediomastus californiensis* became dominant in the fall-winter periods of 1972-74. No other cases of true dominance occurred. *Tharyx* tended to be the most numerous animal in the summer months.

General Trends. The number of individuals declined in the non-summer periods beginning in 1975 through the present sampling. The multiple grab samples taken from June 1975-March 1977 artificially increased the total taxa figures for this time. There have been no essential changes in the faunistic composition since the AHF, 1976 report (Table 3).

Station A7

No clear temporal patterns were seen in population size or species diversity because of variability. Generally, when population size was large, order-of-magnitude differences occurred between dominant and second-ranking species. In the 23 sampling periods between March 1971 and October 1978 *Armandia bioculata* dominated twice and *Capitella capitata* dominated 18 times. These two species and the nematodes are characteristic of disturbed (variable) or polluted habitats (Reish, 1959) (Table 4).

Numbers of molluscan and crustacean species began increasing in 1978. In July 1978 species diversity was very high for this station. Faunal composition of the October 1978 sampling showed radical differences. The polychaete *Mediomastus californiensis* dominated, and the species found resembled outer harbor or channel faunas.

Station A12

Seasonality. No strong seasonal patterns occurred, although there was a tendency for population size to increase in spring-summer periods (Table 5).

General Trends. The faunal composition has been quite stable at this station, which was one of the richest in the outer harbor. Changes in rank among the four abundant species did happen, but only once, in August 1972, when a single species (*Tharyx*) was dominant.

There has been a decrease in the numbers of individuals collected here since October 1975. Again, multiple grabs taken from October 1975 through March 1977 for other purposes cloud the diversity aspect, but at least permitted maintaining the long-term baseline which would otherwise have been dropped.

Biotic Characteristics of Soft Bottom Habitats

Soft bottomed habitats with easily disturbed sediments favor deposit-feeding organisms. These animals turn over the sediments during feeding or burrowing, impeding to some extent the settlement of suspension-feeding species (Levinton, 1973). However, suspension feeders often cannot tolerate the turbidity levels associated with unconsolidated bottoms. The activities of deposit-feeding animals can turn over the entire bottom of an area in a few years (Gordon, 1966). The outer harbor is an excellent habitat for deposit-feeders.

Enrichment of a benthic community can produce marked increases in the numbers and biomass of animals. In Scotland, enrichment of a sea loch produced a maximum of up to 60,000 animals/m^2 in 3 to 4 years (Raymont, 1950). This is remarkably like the situation that occurred in Los Angeles Harbor in 1973-74 (Figure 10) following pollution abatement in 1970, where numbers up to 80,000/m^2 were encountered within the next four years (AHF, 1976; Soule and Oguri, 1976). This contrasts with the populations seen (Figure 11) after reduction in nutrient wastes.

Tenore (1975, 1977) and Tenore and Gopalan (1974) found that improvement in the nutritional quality of detritus by enrichment was important in the growth of polychaete worms. Proteinaceous wastes or the bacteria and protozoa supported by finely ground sewage wastes served as a better food source for the benthic fauna than fresh plant detritus.

Areas directly under outfalls often have depleted faunas. This may be due to high organic content, toxic components, chlorination turbidity, the impact of fresh water injected into a marine environment, or to other unidentified factors. Deposit feeders in such areas often cannot turn over the sediment swiftly enough to prevent decomposition in areas with high organic content (Nichols, 1974); however, no excessive buildup has been seen in the Los Angeles Harbor outfall area. Pelecypods increase in abundance with up to 3% organic content, but decline at greater concentrations in the sediment due to decomposition and anoxic conditions (Bader, 1954). Concentrations in the harbor are about 1.5%. Many fishes and invertebrates cannot tolerate the chlorine residues in treated sewage (Emerson, 1976; Bellanca and Bailey, 1977), and toxic chloramines or organics may be formed (Oliver and Carey, 1977). Fresh water used to flush wastes and runoff can prevent settlement of all but the most euryhaline species. Stone and Reish (1965) documented the effects of seasonal rain runoff on recolonization in the Los Angeles River. Such fluctuations are considered healthy for the prevention of a few organisms from completely dominating an estuary or bay.

Around the immediate vicinity of outfalls, species such as *Capitella capitata* are found, which are hardy, opportunistic, fast-growing species that thrive in the absence of competition (Grassle and Grassle, 1974). Although they have often been considered to be indicators of polluted conditions (Reish, 1959; Word, Meyers, and Mearns, 1977), the species occurs in many unstable (variable) environments where rapid growth and short, year-round reproductive cycles give them an advantage.

Beside varying spatially according to the amount of enrichment, benthic animals in the harbors vary in size and quantity according to the season. Like most shallow-water areas, these bottoms receive varying amounts of sunlight, freshwater runoff, and primary production by plants during each year. The reproductive cycles of the invertebrates are attuned to these changes.

The year-class phenomenon, in which recruitment can vary enormously from year to year, is prevalent (Grassle and Sanders, 1973). The combination of spatial and temporal patterns produces a shifting mosaic of benthic populations.

CONCLUSIONS

The benthic invertebrates found in outer Los Angeles-Long Beach Harbors are species generally characteristic of soft bottom habitats. Polychaete worms, gammarid amphipods (small shrimp-like crustaceans), and small clams are common. Ghost shrimp (genus *Callianassa*), sea pens, gaper clams (*Tresus nuttalli*), and tube anemones (order Ceriantharia) are among the larger animals in the area.

The general distribution patterns of the harbor have not changed greatly in 1978 from the 1973-74 period (AHF, 1976). There are still gradations from inner to outer harbor and from the outfalls area to the outside of the breakwater.

The populations in the enhanced area (Soule and Oguri, 1976) numbered greater than 25 species and 35,000 individuals per m^2 in 1973-74.

The mean number of species/m^2 rose four-fold from 1971 (14) to a high in 1976 (57). It has now dropped to pre-1973 levels (41), (Figure 2; Table 1).

The mean number of individuals/m^2 rose from about nine-fold between 1971 and 1973, the peak; the mean declined by 15% of 1974 levels in 1975, by a severe 56% of 1975 levels in 1976, and leveled off in 1977. There was another small drop in 1978, placing the 1976-78 means at less than half the 1972 level.

Thus, both species numbers and population numbers have dropped over the last three years, precisely the period when so-called cleanup measures were instituted for cannery and sewage wastes. This cannot be blamed on rainfall, or lack of it, because rainfall was low in the winter of 1972-73, yet counts rose dramatically in 1973. The winter of 1975-76 had low rainfall, but populations declined.

A nearly four-fold decrease in benthic organisms between 1973 and 1978 represents a severe drop in the food supply of obligate or facultative benthic feeders such as demersal fish species and invertebrate predators. At station A1, declines in the two major species *Tharyx* sp. and *Mediomastus californiensis (Capitata ambiseta)* are notable since this would indicate a decrease in enrichment at the perimeter of the harbor.

LITERATURE CITED: See Section VI.

Table 1.

Annual Mean Numbers of Benthic Species and Organisms Per M^2.
(#species/#organism)

Stations	1971	1972	1973	1974	1975*	1976*	1977*	1978	Mean
A1	16/553	52/ 7,347	54/ 6,645	68/10,580	62/ 6,706	79/ 2,300	49/ 2,580	40/ 1,560	53/ 4,784
A2	24/ 4,117	52/29,284	66/35,360	64/38,296	62/18,133	65/17,060	74/10,993	46/ 4,412	57/19,707
A3	18/ 3,213	51/24,089	53/16,395	52/17,836	62/11,353	73/ 6,472	64/ 8,000	47/ 4,949	53/11,538
A4	4/ 1,345	19/17,169	6/ 8,331	7/ 2,728	17/ 9,910	23/ 1,932	50/15,363	30/ 9,128	20/ 8,238
A5	4/90	10/ 6,074	15/10,192	4/684	15/19,040				10/ 7,216
A6	5/77	4/178	10/12,272	6/ 2,332	29/54,064				11/13,785
A7	7/ 1,680	14/ 6,603	14/12,256	17/ 7,930	10/ 2,665	8/808	6/ 3,737	19/11,185	12/ 5,858
A8		39/30,362	57/55,093	58/21,000	54/ 3,600	71/ 5,640	48/ 1,813	42/ 8,244	53/17,965
A9	36/11,810	44/32,118	47/45,456	46/37,900	44/16,155	71/24,952	48/11,370	36/ 9,512	47/23,659
A10		44/19,984	48/53,520	47/28,616	51/36,464			48/21,851	48/32,087
A11			64/21,880	54/26,040	48/13,961	68/ 5,220	62/ 6,408	32/ 5,701	55/11,316
A12		60/28,200	66/29,280	59/30,864	62/13,161	55/ 4,790	63/ 7,843	42/ 4,808	58/16,992
A13							69/15,970	48/ 5,068	59/10,519
A14							39/ 1,590	41/ 5,845	40/ 3,718
A15							49/ 6,450	39/14,836	44/10,643
A16							58/ 4,600	48/ 6,560	53/ 5,580
A17							43/ 2,740	50/ 4,715	47/ 3,728
B8		50/ 9,940	61/41,403	62/34,012	62/15,728		69/16,290	46/ 3,888	58/20,210
B9		50/ 9,420	66/41,200	58/27,008	60/21,696			48/ 4,240	56/20,713
Mean	14/ 2,861	38/16,982	45/27,806	43/20,416	46/17,331	57/ 7,686	53/ 7,716	41/ 7,441	42/12,987

* multiple grabs increased diversity

Table 2. Benthic Species at Station A1, 1978.

Abundant Species

Polychaeta:	% of Total Indiv.
Mediomastus californiensis (formerly *Capitita ambiseta*)	21%
Tharyx sp. (*Tharyx* ?parvus)	9%
Prionospio (*Apoprionospio*) *pygmaeus*	4%
	34%

Common Species

Polychaeta:

- *Prionospio steenstrupi* (formerly *P.* nr.*malmgreni*)
- *Chaetozone setosa*
- *Sigambra tentaculata*

Mollusca:

- *Parvilucina tenuisculpta* (*Parvilucina* sp.)
- *Tellina modesta*
- *Mysella pedroana*

Table 3. Benthic Species at Station A3, 1978.

Abundant Species

Polychaeta:	% of Total Indiv.
Mediomastus californiensis (formerly *Capitita ambiseta*)	32%
Tharyx sp. (*Tharyx ?parvus*)	15%
Prionospio (*Minuspio*) *cirrifera*	4%
Cossura candida	3%
	54%

Common Species

Polychaeta:

- *Lumbrineris*
- *Nephtys cornuta franciscana*
- *Nereis procera*

Mollusca:

- *Tellina modesta*
- *Macoma nasuta*
- *Parvilucina tenuisculpta* (*Parvilucina* sp.)
- *Protothaca* sp. juveniles

Table 4. Benthic Species at Station A7, 1978.

Abundant Taxa

	% of Total Indiv.
Polychaeta:	
Capitella capitata	55%
Armandia bioculata	5%
Polydora ligni	2%
Nematoda:	
Unidentified nematodes	13%
	80%

Table 5. Benthic Species at Station A12, 1978.

Abundant Species

	% of Total Indiv.
Polychaeta:	
Tharyx sp. (*Tharyx ?parvus*)	37%
Cossura candida	17%
Mediomastus californiensis (formerly *Capitita ambiseta*)	17%
Tauberia oculata (formerly *Paraonis gracilis oculata*)	6%
	77%

Common Species

Polychaeta:
- *Nephtys cornuta franciscana*
- *Chaetozone corona*
- *Lumbrineris*

Mollusca:
- *Parvilucina tenuisculpta* (*Parvilucina* sp.)

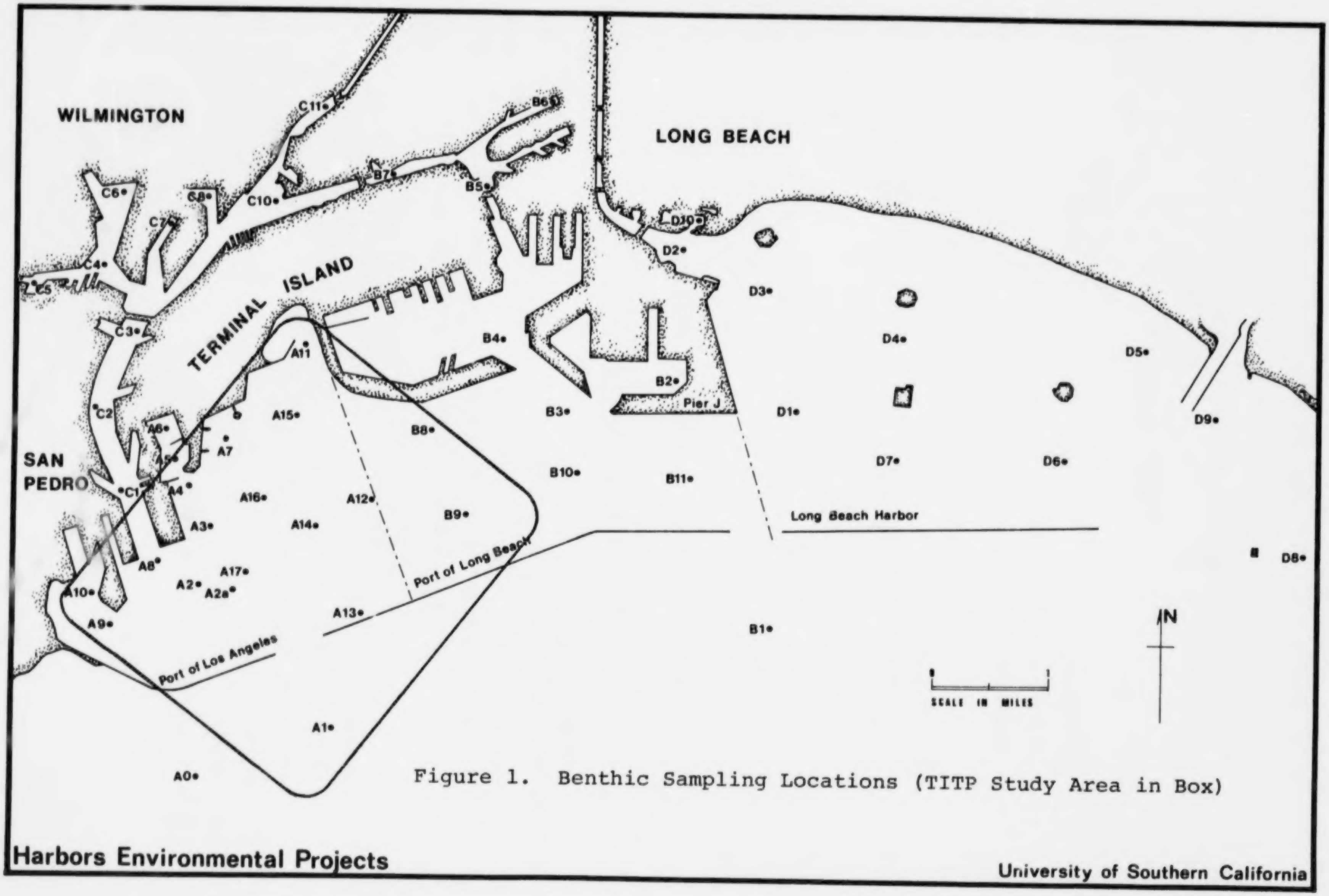

Figure 1. Benthic Sampling Locations (TITP Study Area in Box)

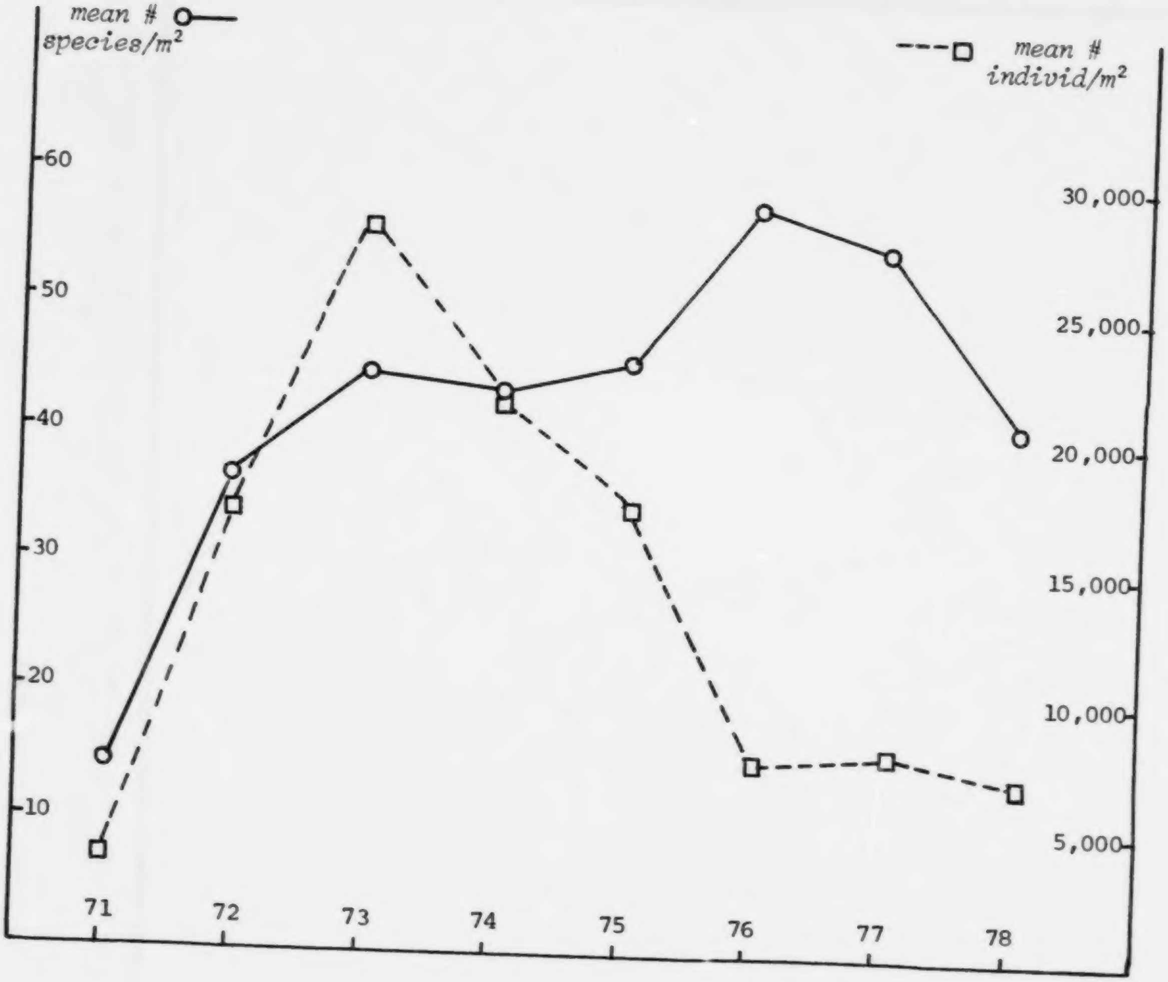

Figure 2. Annual means of benthic species and number of benthic individuals/m^2 for stations sampled, 1971-1978. (multiple grabs enhanced diversity in 1975-77)

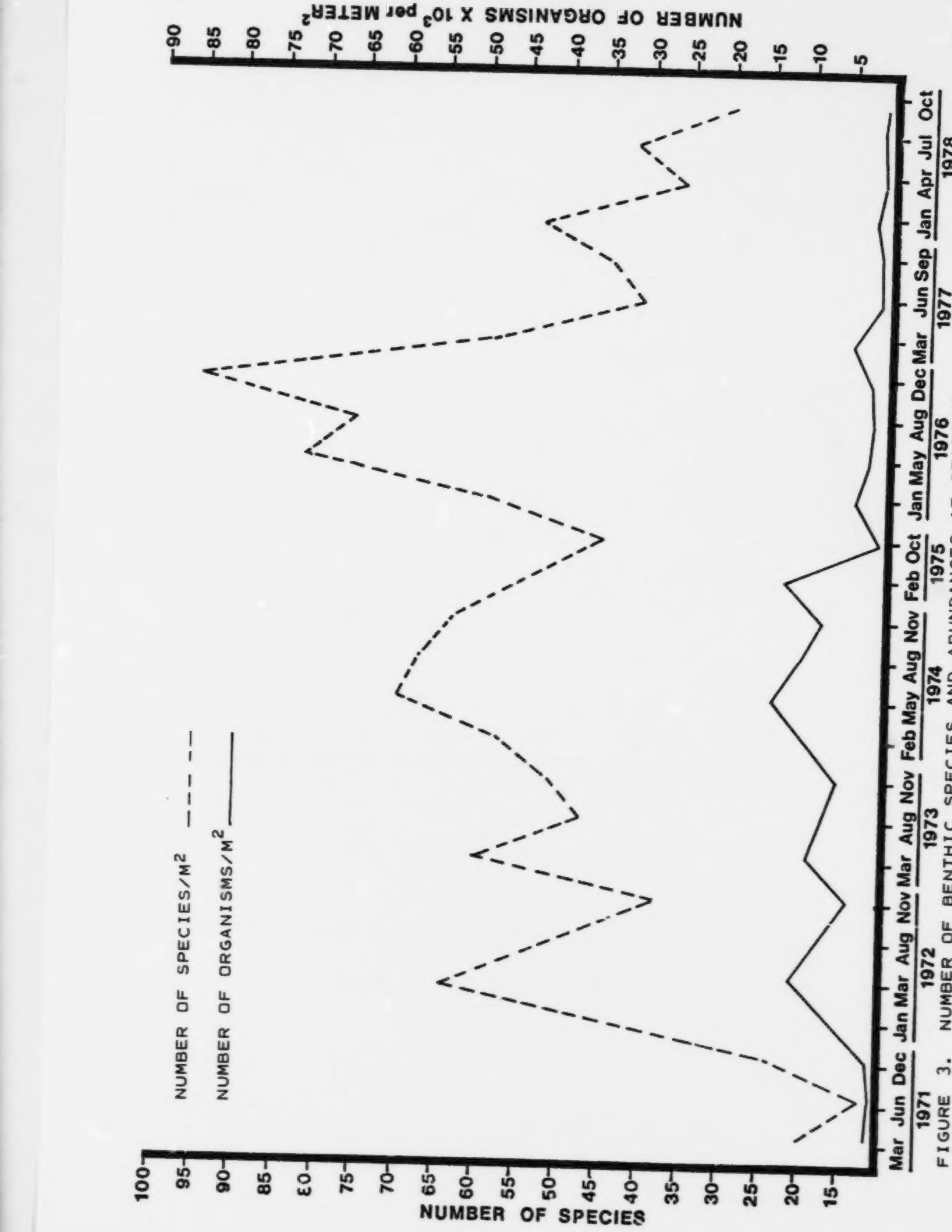

FIGURE 3. NUMBER OF BENTHIC SPECIES AND ABUNDANCES AT STATION A1 OUTSIDE LOS ANGELES HARBOR, 1971-1978

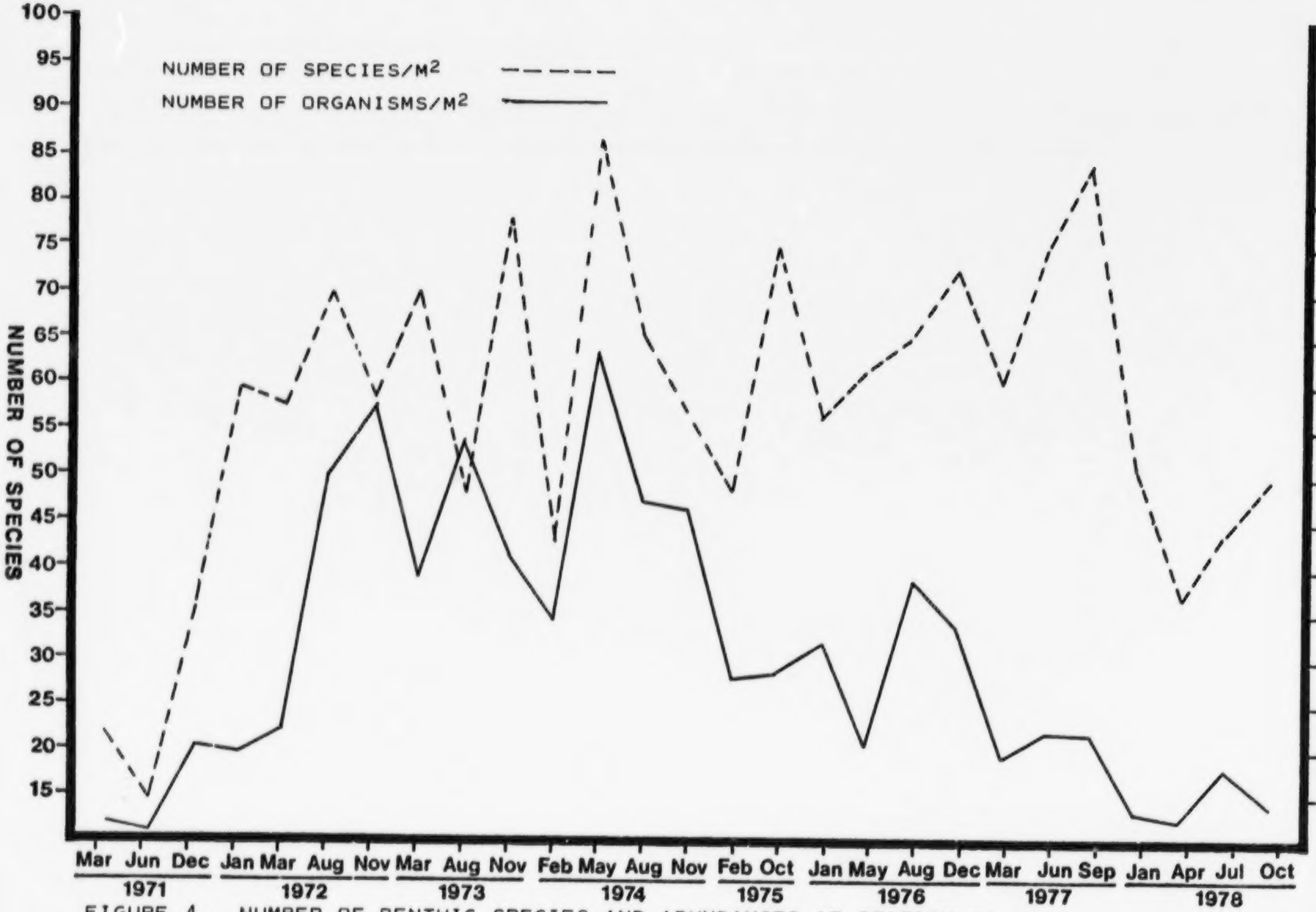

FIGURE 4. NUMBER OF BENTHIC SPECIES AND ABUNDANCES AT STATION A2 OUTSIDE LOS ANGELES HARBOR, 1971-1978

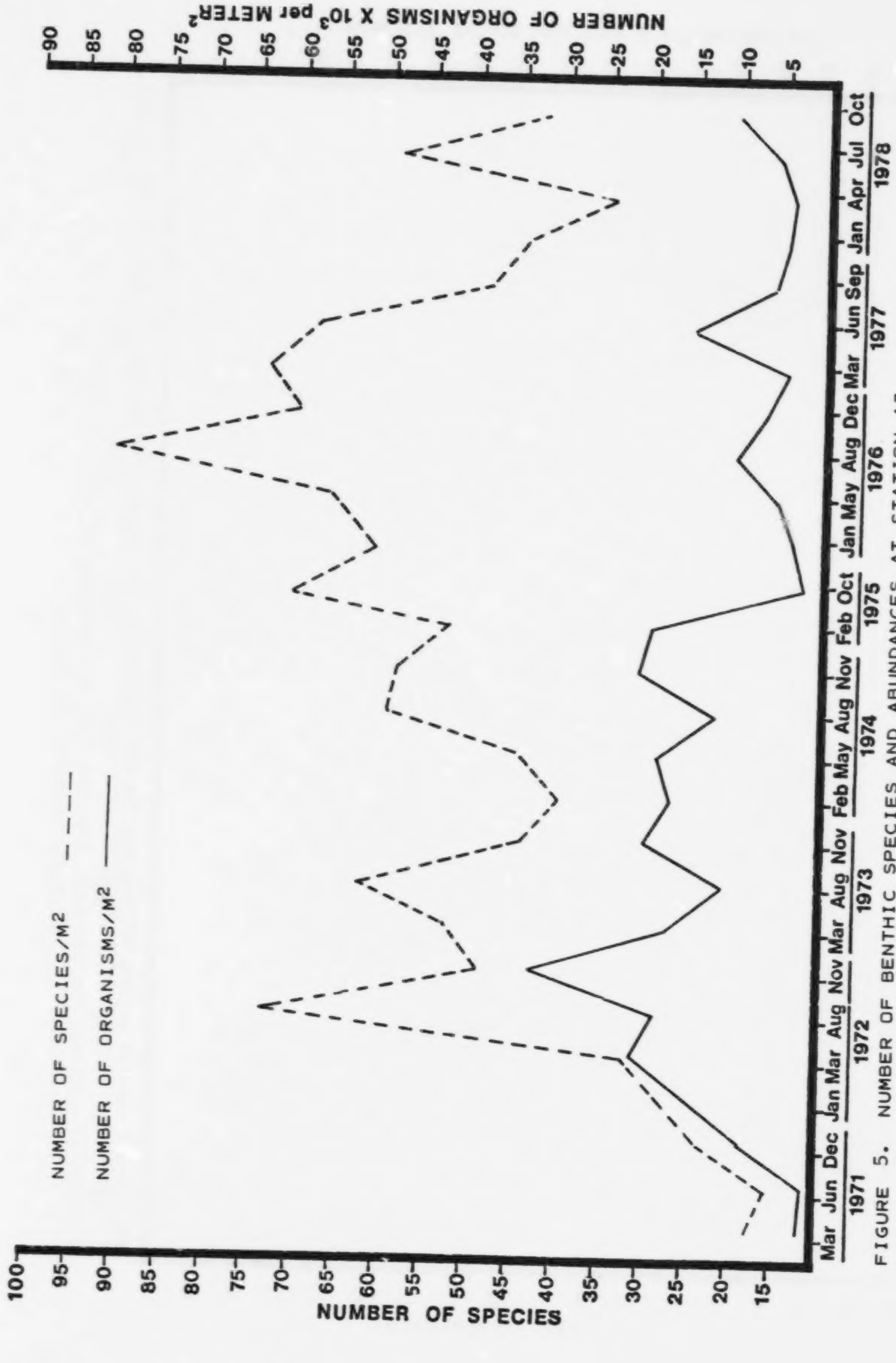

FIGURE 5. NUMBER OF BENTHIC SPECIES AND ABUNDANCES AT STATION A3 OUTER LOS ANGELES HARBOR, 1971-1978

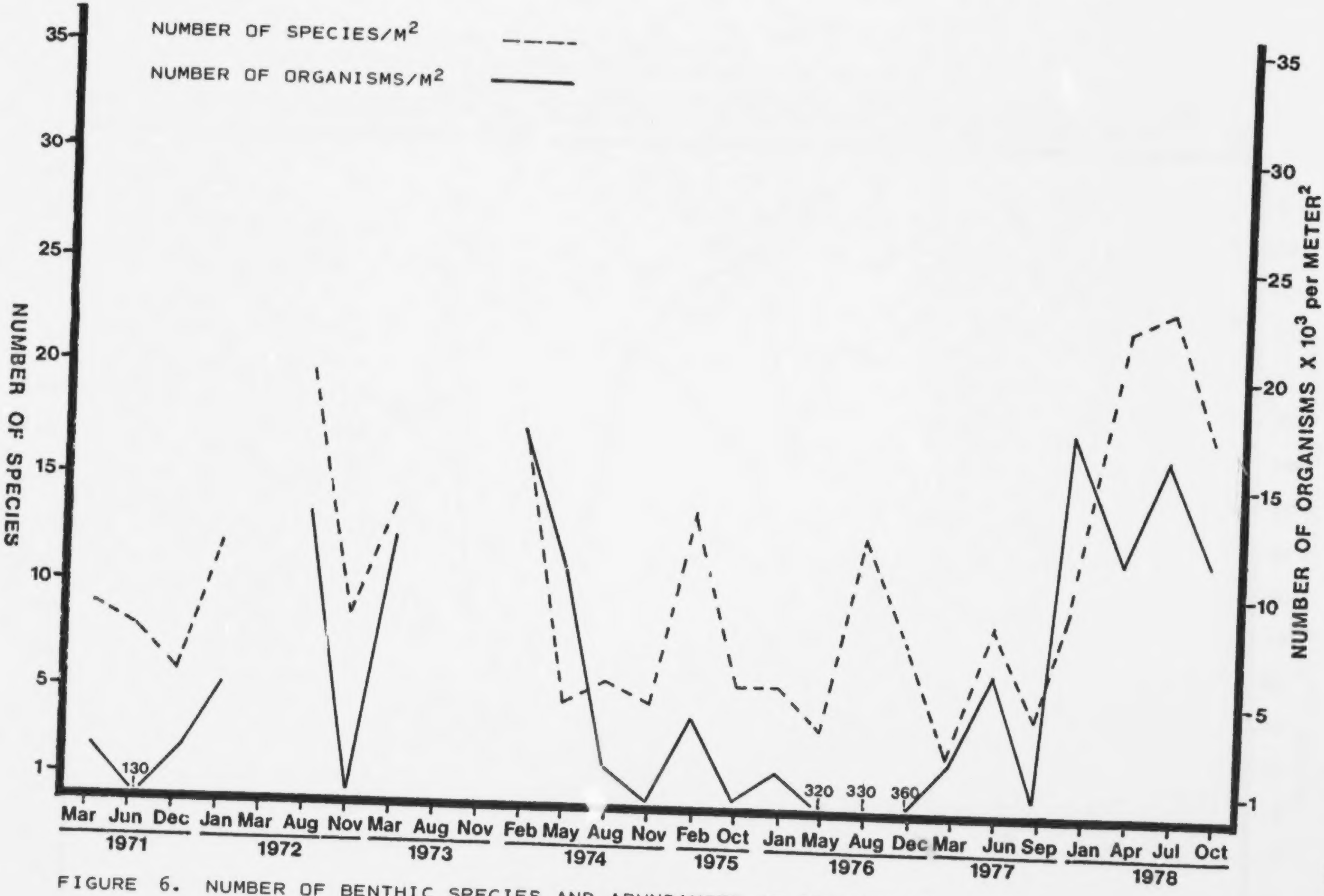

FIGURE 6. NUMBER OF BENTHIC SPECIES AND ABUNDANCES AT STATION A7 OUTER LOS ANGELES HARBOR, 1971-1978

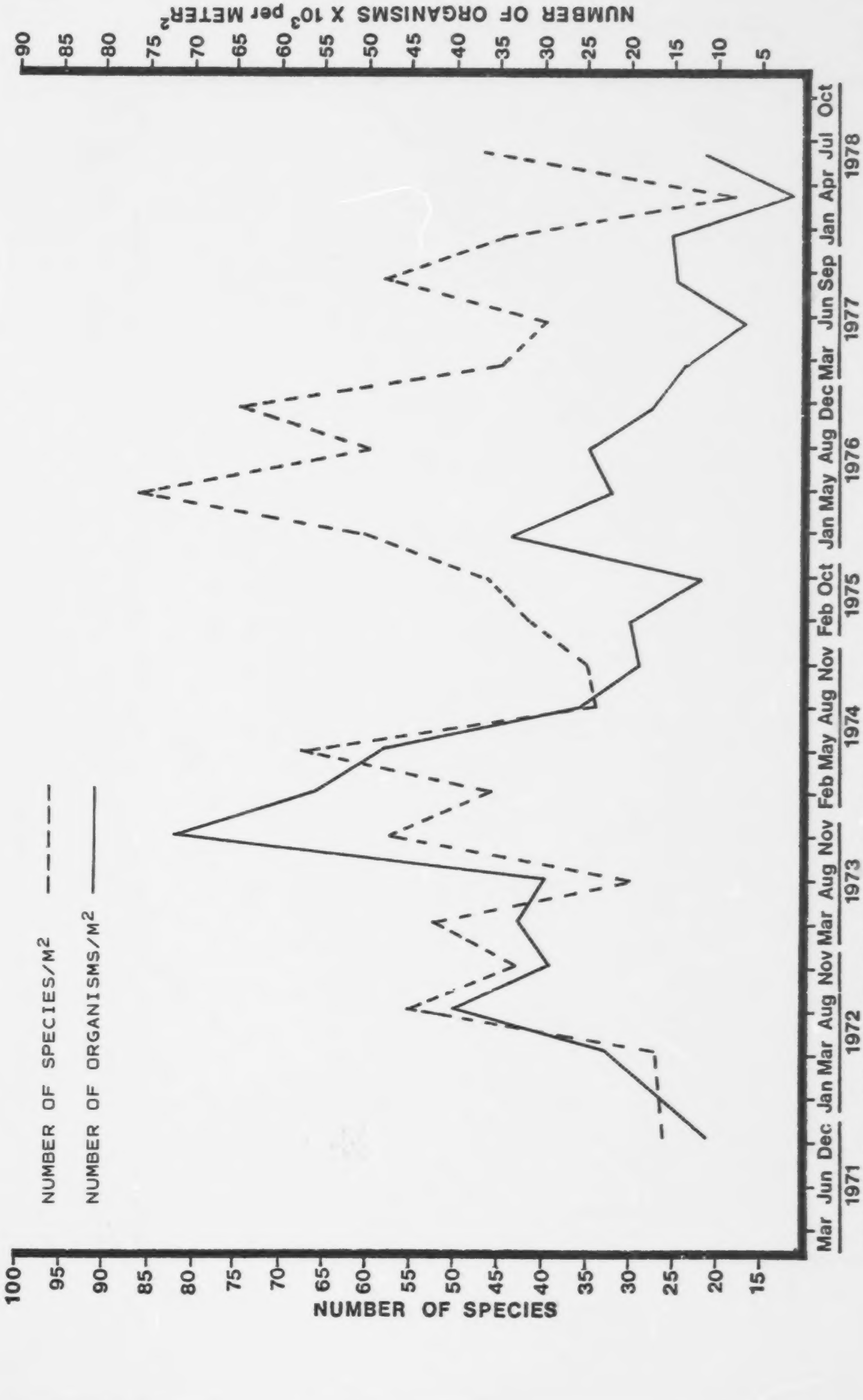

FIGURE 7. NUMBER OF BENTHIC SPECIES AND ABUNDANCES AT STATION A9 OUTSIDE LOS ANGELES HARBOR, 1971-1978

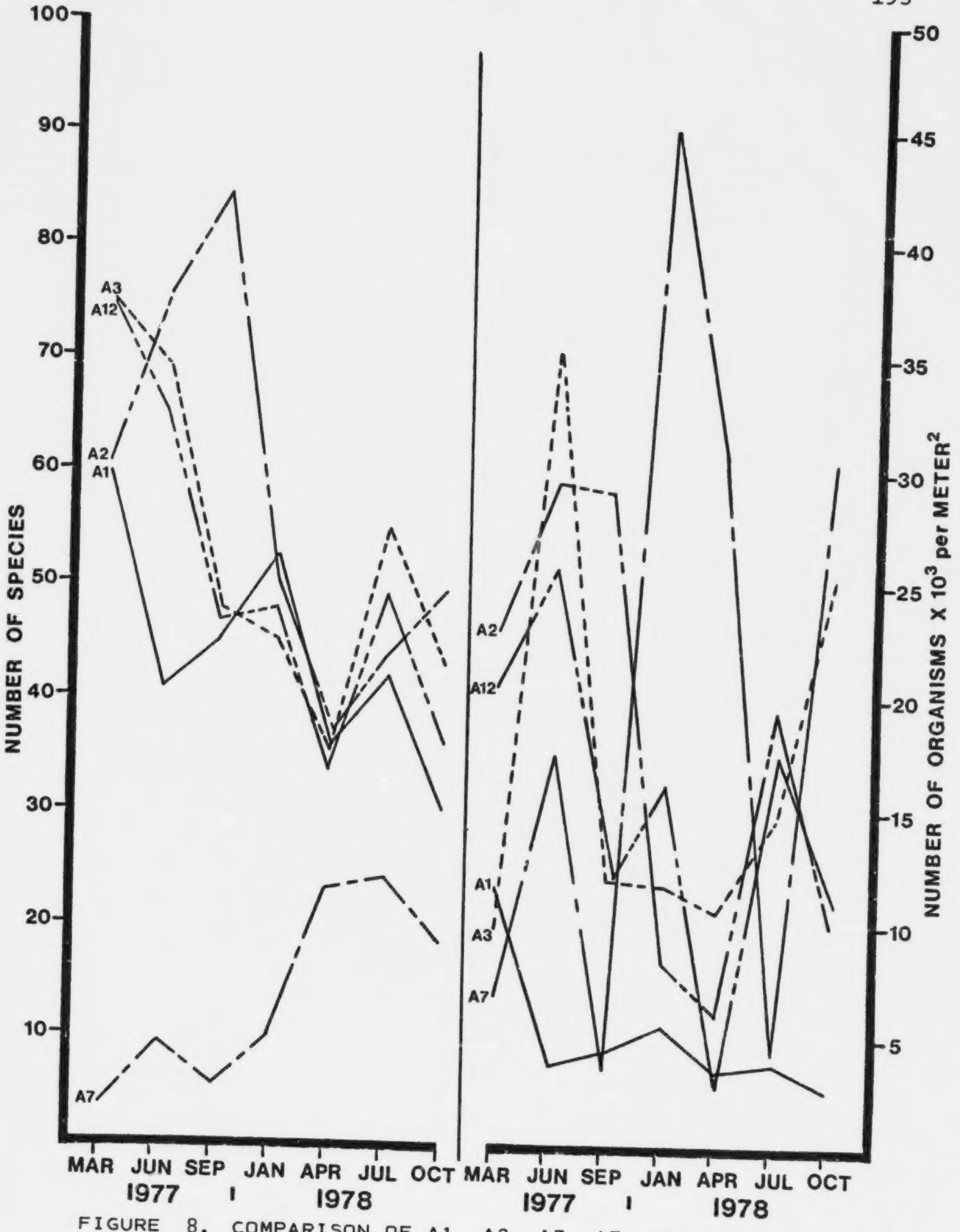

FIGURE 8. COMPARISON OF A1, A2, A3, A7, AND A12, 1977-1978

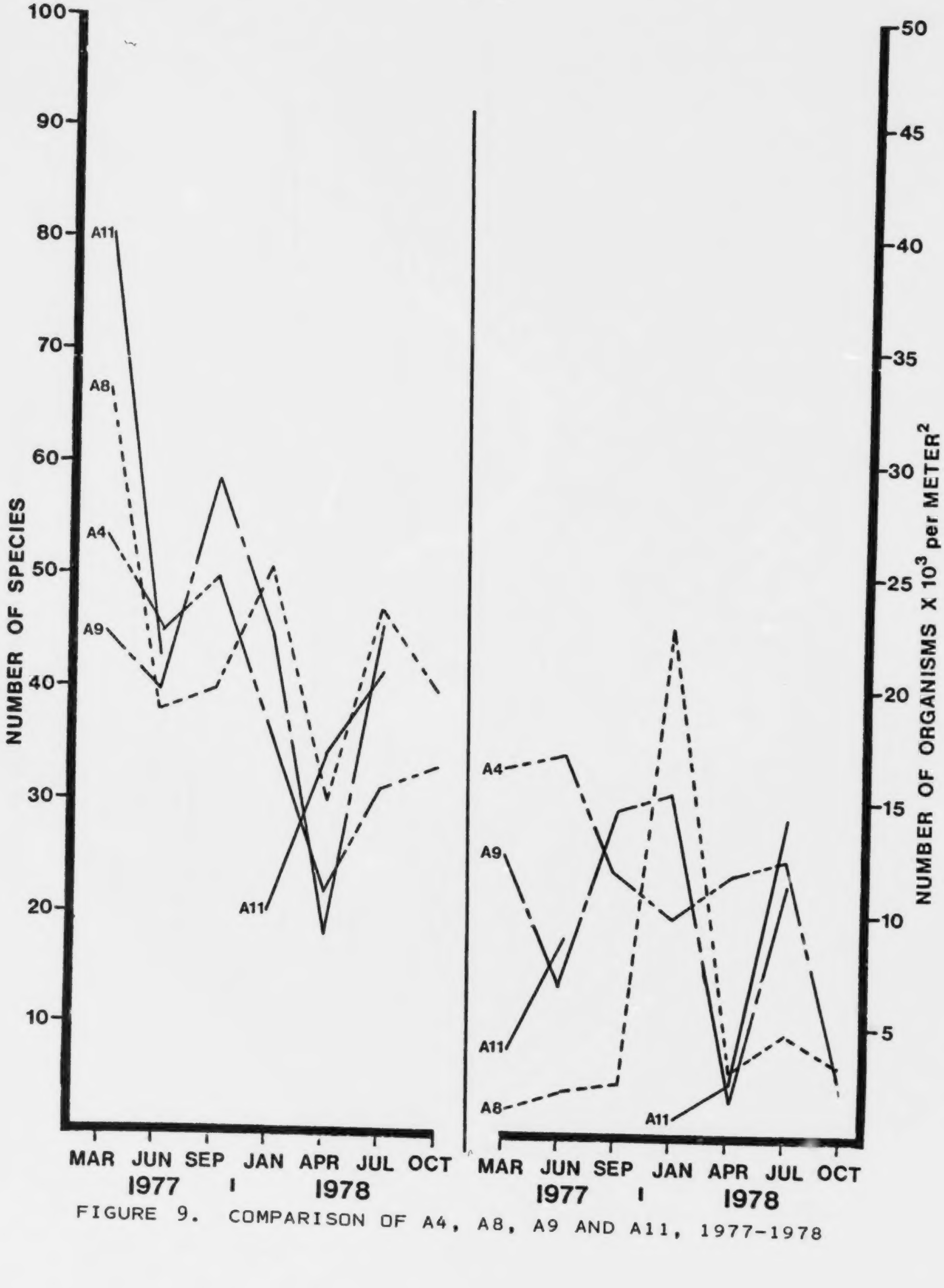

FIGURE 9. COMPARISON OF A4, A8, A9 AND A11, 1977-1978

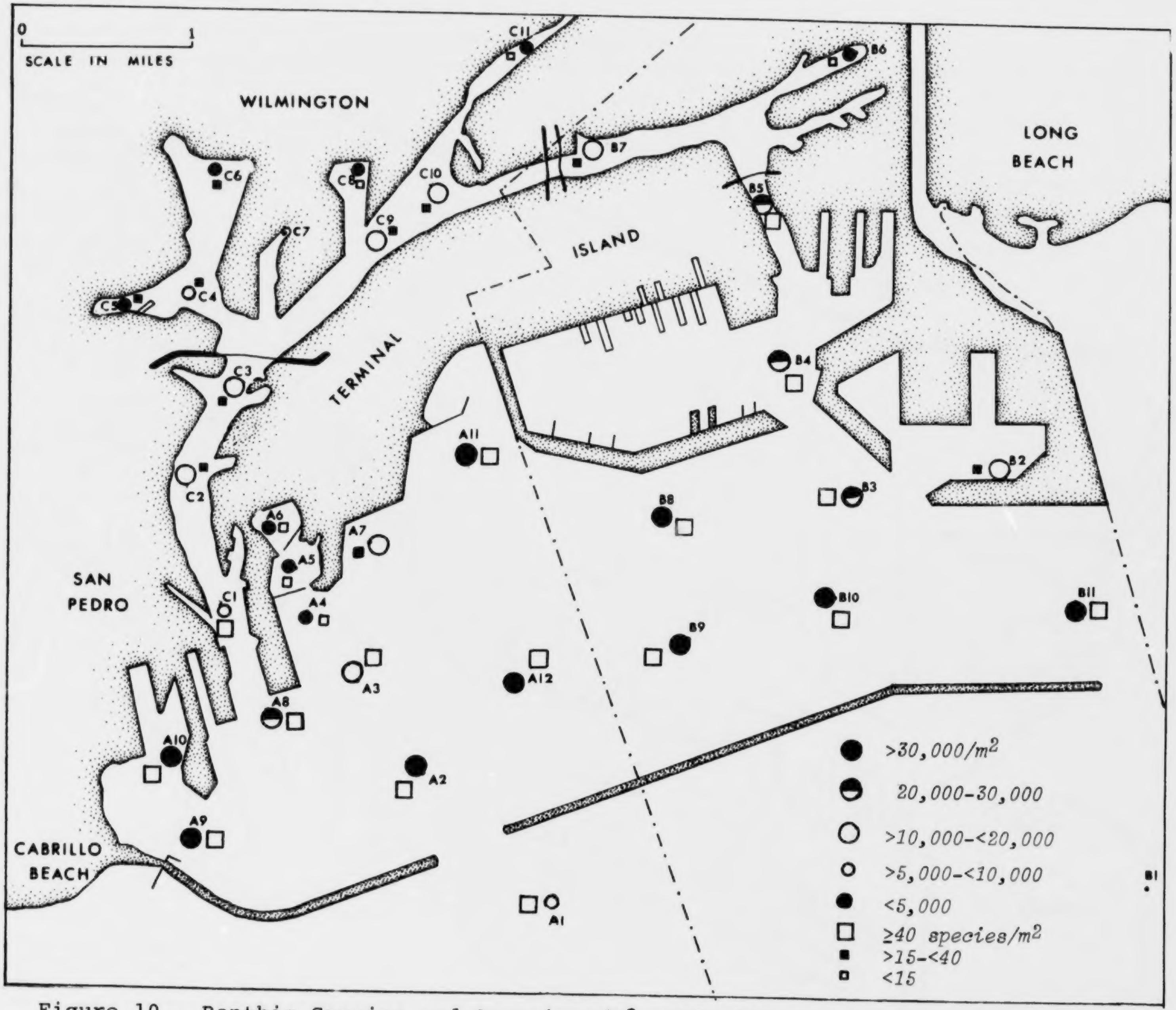

Figure 10. Benthic Species and Organisms/M^2, 1973-1974.

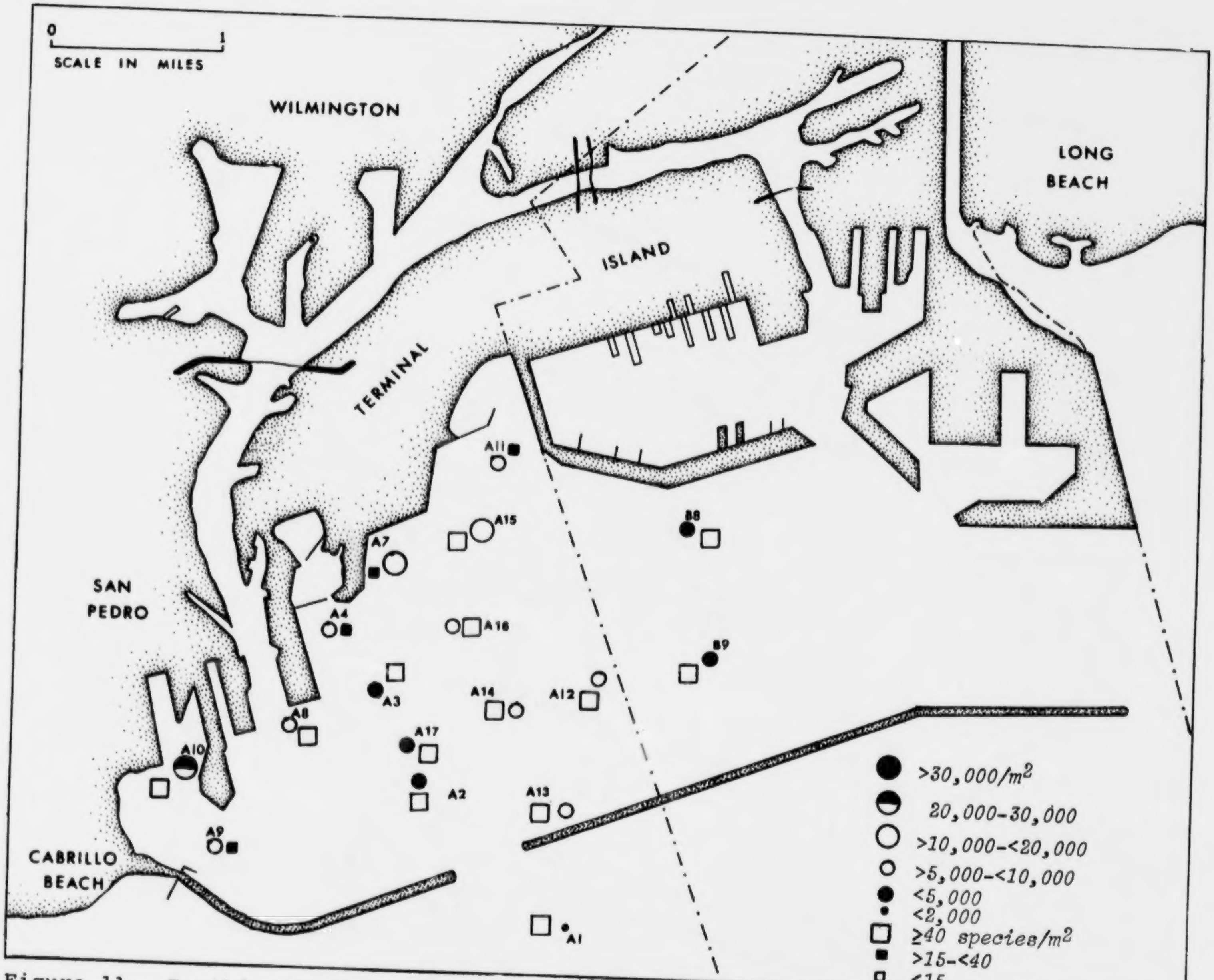

Figure 11. Benthic Species and Organisms/M^2, 1978.

FISH EGG AND LARVAE SURVEYS

INTRODUCTION

The Los Angeles-Long Beach Harbor complex was shown to be rich in fish species and numbers in 1972-1974 (Stephens, 1974; AHF, 1976) and to be an important nursery grounds for larval fish (AHF, 1976). The latter study emphasizing the anchovy population sampled eggs and larvae from February 1973 through September 1974 at forty stations in San Pedro Bay.

In an effort to update information about larval fish population following initiation of secondary treatment in 1977 of cannery and domestic sewage discharge into the harbor, new studies were initiated in 1978 for the City of Los Angeles Terminal Island Treatment Plant.

During the initial study, anchovy (*Engraulis mordax*) eggs and larvae were sampled by means of horizontal tows at 4 m depth. Since the initial study, the spawning stock of anchovies in the harbor has decreased by two orders of magnitude (Frey, personal communication); consequently the sampling program was altered to effect capture of larvae from all parts of the water column and to produce data comparable with egg and larvae surveys conducted by National Marine Fisheries Service (NOAA) (Kramer *et al.*, 1972).

Understanding of spawning behavior, seasonal periodicity, environmental factors and species interactions of commercially important fish taxa have been investigated by a variety of governmental and private concerns. Recently the emphasis has been expanded to consider under-utilized or non-utilizable fish resources.

The scope of this study encompassed factors that affect larval population and adult population dynamics.

Concurrent with this investigation a monthly monitoring program characterizing the abiotic and microbiotic parameters of the harbor was conducted by Harbors Environmental Projects; concurrently, trawls to assess adult fish populations were being conducted by Stephens (Section IIA). Data generated by those studies are presented to augment understanding of some of the factors affecting larval fish populations. As knowledge of all phases of the harbor ecosystem is increased, there is a concomitant increase in the capacity to assess and predict the effects of fluctuations or perturbations.

It appears from the studies conducted over the last five years that adult populations of the numerically dominant species (*Genyonemus lineatus* and *Engraulis mordax*) have been declining. The present study has attemped to provide information from ichthyoplankton and other data that will assist in exploring the possible causes of this decrease.

MATERIALS AND METHODS

Ichthyoplankton populations were sampled in the Los Angeles-Long Beach Harbor area at ten stations (Figure 1) over a period from January through November 1978. The earlier study (AHF, 1976) sampled these ten stations as well as an additional thirty, in the same general area.

In the original ichthyoplankton study, a 0.5 m plankton net (333µ mesh) was towed at 4 m depth from a small boat at low speed. In the current study, oblique tows using 333µ mesh bongo nets were taken from the R.V. *Golden West* (Figure 2), such that while the boat was in motion, the nets descended towards the bottom as cable was released and ascended to the surface while cable was retrieved. From April through November 1978, a second sampling method was added, a 0.5 m plankton net (333µ), towed for five minutes from the R.V. *Golden West* near the surface (< 1m). The cod ends of both nets in the current study were provided with screens of mesh size similar to that of the nets. Bongo nets were equipped with a rocket-shaped flow meter (General Oceanics); the 0.5 m ring net was equipped with a four-blade, four-dial flow meter (Rigosha).

Table 1 summarizes the monthly sampling regime at each station. During the first three months (January-March) bongo tows were conducted at night. To facilitate comparison of data with earlier studies employing different sampling methods, additional 0.5 m net tows were taken during the day for the remainder of the study.

Samples were fixed on shipboard with buffered formalin and returned to the laboratory for identification. Eggs were sorted and counted, and engraulid eggs were further separated and tabulated. Larvae were sorted and grouped by general characters, and then identified to the lowest possible taxonomic level (family, genus or species), except for unidentifiable, "unknown" specimens. Literature references concerning early life histories of marine fishes, as well as an established reference collection, provided a source of comparison for identification. A reference collection consisting of larval specimens from the current study was established and identifications were verified by personnel of the National Marine Fisheries Service, La Jolla, California. Counts were tabulated and a conversion factor based on flow meter data was used to quantify number of larvae or eggs in $\#/m^3$ of water sampled.

Concurrent with this study, the Harbors Environmental Project was sampling forty stations monthly in Los Angeles-Long Beach Harbors. Data gathered on dates and at stations correspondingly close to trawl dates and ichthyoplankton stations (A1, A2, A4, A7, B9, B10, B11, C3) were assimilated into composite monthly averages to provide necessary background for interpretation of ichthyoplankton data.

Surface water was collected by bucket at each station, and samples were taken for nutrient analysis (nitrate, nitrite, ammonia and phosphate levels) in the laboratory. Samples were filtered on board for spectrophotometric chlorophyll *a* analysis in the laboratory. Nutrient and chlorophyll analyses were performed according to Strickland and Parsons (1972); Section I, this volume. Temperature and salinity data were taken with a Mark V Martek Corp. remote probe unit.

RESULTS

Abiotic Data and Phytoplankton

Surface temperatures in the harbor (Figure 3) fell from a year-end high in 1977 (17.3°) to a winter low of 15.4° in January 1978, rose through the spring, and fell off in early summer in July. Temperature resumed an upward trend toward a maximum in October (20.4°) and then fell rapidly through November and into December. Salinity values fluctuated for the first four months of the year, leveled off in March through October and then began to increase toward a seasonal high later in the year.

Figure 4 shows values for two of the primary nitrogen sources available to photosynthetic algae and bacteria. Nitrite (NO_2) levels remained fairly constant (.11-.27 µg-at N/l) throughout the year except for a protracted peak between July and September. Nitrate (NO_3) levels increased through the early part of the year and then fell abruptly to a low summer plateau, increasing in the fall. Figure 5 shows the mean values of ammonia nitrogen (as NH_4) and phosphate (PO_4) phosphorus. Ammonia values follow those of the nitrate sources, while phosphorus levels remain fairly stable.

The seasonal fluctuation in harbor chlorophyll *a* levels, a measure of plankton biomass, is shown in Figure 6. Values are low during the early part of the year (1-2 mg Chl a/m^3) increased to a high in September and showed another maximum in November (5 mg Chl a/m^3).

Ichthyoplankton

Displayed in Figure 7 are the seasonal variations in egg and larval stocks in the harbor area for 1978 and for the original study in 1974, expressed as mean number/100m^3 of water filtered. The largest incidence of eggs and larvae for both studies occurred in the early part of the year (January-March). 1974 data are taken from Figure 7.6 of the orginal study, which represented numbers of all eggs and larvae other than from anchovies. (Information elsewhere in the text showed engraulid data to be significant only in the first three months, where they provided a modest increase, *e.g.* total larvae including anchovies peaked at 103/100m^3 in February.) While the patterns of seasonal variations are similar for both 1978 and 1974, concentrations are greater by orders of magnitude in 1978 than in 1974. Differences in collection depth would have influenced this increase to some extent, as discussed in a later section.

While abundance of larvae is at a maximum in the early part of the year, Figure 8 illustrates that the number of species of fish spawning has two peaks; one in the early part of the year and then one in fall.

Over the course of the year the abundance and composition of the ichthyoplankton population varied greatly. In the initial part of the year larger numbers of sciaenid larvae (white croaker, *Genyonemus lineatus*) dominated larval counts; the majority of the correspondingly high numbers of eggs were also probably from sciaenids. Table 2 represents a taxonomic breakdown of eggs and larvae encountered in this study, identified to the lowest possible taxonomic level or, occasionally, a most likely choice when absolute identification could not be made (*e.g. Paralichthys/Xystreurys*).

Table 3 lists larvae identified in Table 2 in descending order of abundance, both as total numbers of larvae captured and as number/100m^3/yr. Also listed for each larval form are the numbers of samples (62 total) at which each occurred as well as the number of months (out of a possible 9) in which each was seen. The sciaenid species *Genyonemus lineatus* and engraulid larvae constitute the two most abundant larvae encountered, while gobiid and engraulid larvae showed the highest numbers of occurrences.

Species Distributions

Figures 9 and 10 show the distributional pattern of eggs and larvae throughout the harbor. Station 4, nearest the cannery outfall area and TITP discharge areas showed high numbers of eggs and larvae. Station 2, near the entrance of the harbor also showed high numbers of eggs.

Figures 11, 12, 13 and 14 represent stations which showed the highest numbers of larvae captured for the four top-ranking larvae encountered. The majority of Engraulidae larvae were still found outside the breakwater (Figure 11), as was true in the earlier surveys (AHF, 1976). Water movement into the harbor through the gates probably carried large numbers of larvae into the station near the entrance. Abundance decreased as the larvae are carried further and further into the harbor. The lowest abundances were found in the outfall area and in the Long Beach Back Channel as in the earlier studies.

Figure 12 illustrates the pattern of larval abundance of the Sciaenidae, principally *Genyonemus*. As in the original study, sciaenids showed large concentrations in the Back Channel (St. 17) and around the outfall area. Environmental Quality Analysts/Marine Biological Consultants (1978) reported that *Genyonemus* adults comprised 49% of other trawl collections from Long Beach harbor, where the majority of stations were in the Back Channel.

The Gobiidae data show (Figure 13) that most of the larvae stay near the areas of rocky habitats preferred by the adults. As in the last study, the most productive stations were those in the channels and near the breakwater. Figure 14 for the Blenniidae also shows that station 17 was an area of high larval abundance, as well as station 5. The blenny larvae were found near the environments of the more stationary adults, as were the gobies. But unlike the gobies, blennies did not show significant numbers of larvae around station 16. Both families have eggs that attach to the habitats, so they would not contribute to the eggs found in the survey.

Table 4 compares the larvae from plankton tows and the adult fish taken by the trawls for both 1974 and 1978. Each is ranked by abundance of total numbers captured. Of the most abundant larvae captured for 1978, only the midwater myctophid, *Stenobrachius*, is unexpected, though it has been shown to come inshore to spawn. Two of the ten most abundant adult species, *Phanerodon* and *Hyperprosopon*, are live bearers (embiotocids) with larvae well developed at birth; these would show a high incidence of net avoidance. No representatives of gobies or blennies were found in Stephens' adult fish trawls among the ten most abundant species, while both figured predominantly in larval tows; however, Environmental Quality Analysts/Marine Biological Consultants (1978) data showed that *Lepidogobius* ranked third in abundance prior to thermal input, decreasing in abundance to a rank of tenth afterward.

Clinids and the pomacentrid *Chromis* showed high numbers of larvae in 1974, and fewer in 1978. Some of the explanation lies in the restricted area of the 1978 tows. The tows for the present study were confined to the harbor proper and immediately outside. Clinids and pomacentrids in 1974 showed larval abundances outside the harbor generally, concentrating in an area outside the scope of this study. The only larvae which were dominant in 1974 inside the harbor and which were not dominant in 1978 were representatives of the Cottidae. Members of this family, commonly called sculpins, do occur in the harbor. Several genera, *Clinocottus*, *Leptocottus* and *Scorpaenichthys*, occur at numerous locations around rocky habitats such as the breakwaters and rocky shores of Terminal Island. A reason for their decline in larval abundance cannot be conjectured because of lack of sufficient information about the population dynamics and habits of the adults.

Seasonality

The highest rate of spawning activity, which occurred in January, February and March, coincided with seasonally high levels in chlorophyll *a* concentrations. During this period two families, the Sciaenidae (*Genyonemus*) and Engraulidae (probably *Engraulis*), accounted for 93% of the larvae captured (62% and 31%, respectively). Since the pattern of egg spawning should correspond with the larvae in the area, it can be assumed that the preponderance of eggs were also sciaenid.

Abundance figures in 1978 are 20 times those in the previous study for the first three months (Figure 7) although this is biased by the collecting methods and is not quantifiable with accuracy. A decrease in larval numbers followed during the spring and summer, with an increase from September through November, corresponds with the maximum numbers of about 20 species of fish larvae collected in February and September (Figure 8). The larvae and eggs develop faster in the summer with the increased temperature and therefore settle faster. Coupled with reduced numbers of adults spawning, the abundance of eggs and larvae would be expected to be lower in summer.

Larval fish reached the lowest levels in August. In the present study, August was the first month in which surface samples were analyzed quantitatively. The decrease shown was probably due to differences between bongo and surface tows. Abundance returned to June levels in September and November where surface tows also were taken. Comparison of data for simultaneous surface tows and bongo tows showed that the former method underestimated abundance by a factor of 10 as compared to bongo net totals.

The species using the harbor area as a spawning ground showed a periodicity paralleling phytoplankton peak biomass as noted previously in Figures 7 and 8. A spring bloom and fall bloom put large concentrations of cells in the water which can possibly be utilized by larvae. Some of the species showed spawning throughout the year (*Hypsoblennius* and engraulids). Others showed spawning restricted to the winter/spring period of January through April (*e.g.*, *Genyonemus* and *Stenobrachius*), or the fall period of August through November (*Peprilus*, *Symphurus*, and *Oxyjulis*).

DISCUSSION

The Los Angeles-Long Beach harbor system is a complex ecosystem, adjusting to influences of natural processes and accommodating discharge of urban waste and sewage effluents from commercial and industrial concerns. The effects of a quiet water harbor environment and input of effluents have combined to produce a near-eutrophic system with high production estimates at all levels.

Attempts have been made by the City of Los Angeles and the Regional Water Quality Control Board to improve water quality throughout the harbor system over the past five years, in compliance with federal legislation. Part of the "clean-up" activities focused on the fish cannery facilities and the discharge of processing wastes into the harbor. In 1975 the canneries began to put discharge through dissolved air flotation (DAF) systems to reduce the suspended solids released to the harbor. In the spring of 1977, the Terminal Island Treatment Plant initiated secondary treatment of harbor industrial and sewage wastes. In October 1977, one of the two effluents from the canneries was connected to the TITP facility and by January 1978 the second was connected, subjecting the process water to secondary treatment as well.

In order to assess changes in water conditions it is necessary to compare data from years prior to implementation of treatment with data from subsequent years. Harbors Environmental Projects have collected data since 1971, and published in particular on conditions in the harbor for 1973-74, (AHF, 1974). Included in that volume were data concerning both abiotic and biotic factors, both of which have been considered in the scope of the present study. Other physical and biological data were published in the journal *Marine Studies of San Pedro Bay, California* (Soule and Oguri, eds.).

Abiotic Factors

Temperature and salinity values (Figure 3) over the course of the year reflect seasonal patterns seen up and down the California coast; i.e. water characteristics for the harbor are mediated by water mass factors affecting the entire coast, primarily, variability in the intrusion of the Davidson Current (Oguri, 1974).

In the harbor in the initial part of the year, temperature values approached a mid-winter minimum (15.4 C) and rose through the spring and summer to a fall maximum in October (20.4 C). The 5 degree C change for the entire year reflects the warm water trend the Southern California Bight has been experiencing for the last several years; the minimum was about 4 degrees higher than would normally be expected.

Salinity values in the harbor fluctuated between 37 ppt and 24 ppt during the early part of 1978. This wide oscillation resulted from sampling surface waters during or immediately after rains that coincided with sampling dates. As the rainy season tapered off, the surface salinity values stabilized at approximately 30 ppt and began to increase toward a winter maximum in December. The values found in 1978 were well within the range of values found during 1973 and 1974.

Nutrient values for nitrate nitrogen (NO_3), nitrite nitrogen (NO_2), ammonia nitrogen (NH_4) and phosphate phosphorus (PO_4) are illustrated in Figures 4 and 5. Patterns of maxima and minima for coastal areas have been well documented (Raymont, 1963). The patterns for the harbor were similar, with peaks in values in spring and winter and minima in the summer and fall months.

Nitrate values rise steadily to a spring maximum in March and drop rapidly to minimal values in May. The spring maximum in the harbor coincided with nutrient turnover and increase in NO_3 values found in coastal waters in the early months of the year (Thomas, 1974); flood control runoff entering the harbor during the winter rainy months may also contribute to this peak (AHF, 1976). Nitrite values for the harbor showed a characteristically narrow range, as well as low levels for the entire year, consistent with low levels in the bight region (with the exception of an anomalous peak in August coincident with the TITP malfunction). Ammonia and phosphorus also show typical patterns with the exception of unexpected peaks in midsummer. These peaks also corresponded in time with the breakdown of the TITP plant; the effects of this temporary cessation in secondary treatment will be discussed in a later section.

Text Table 1 compares nutrient ranges for 1974 and 1978. Generally, the nitrogen sources appear to have lower concentrations in 1978 and phosphate levels are slightly higher, but the differences are not large. Considering that in this system medians of ranges are likely to be higher than means using all pertinent data, it appears that both years 1974 and 1978 are similar in nutrient characteristics.

Text Table 1. Nutrient Levels (ug-at/l) in Los Angeles-Long Beach Harbors in 1974 and 1978.

	1974*		1978		
Nutrient	Range	Mean	Range	$Mean_1$	$Mean_2$***
NO_3	1.52-13.86	7.35	0.9-14.2 (69.0)**	5.10	5.37
NO_2	0.12-0.81	.31	0.11-0.27 (3.2)	0.17	0.22
NH_4	0.41-11.9	4.40	1.2-7.8 (60.6)	3.70	4.25
PO_4	0.46-1.75	1.10	0.7-2.4 (6.7)	1.55	1.53

* data from AHF (1976)

** anomalous values from breakdown of TITP plant (in parentheses) are excluded from range of characteristic nutrient levels for 1978

*** $mean_2$ calculated with anomalous values included

Phytoplankton Factors

Nutrient concentrations, temperature and salinity affect adult fish populations primarily indirectly. These factors as well as others (*e.g.*, light levels and silicate concentrations) directly mediate phytoplankton biomass and species succession (Raymont, 1963; Ryther and Dunstan, 1971; Droop, 1973; Rhee, 1974; Tilman, 1977). Phytoplankton biomass, which can be estimated by chlorophyll *a* concentrations, is closely related to peaks in nutrient values, such that large drops in nutrient levels reflect utilization of nutrients by phytoplankton. Normal high nutrient levels and low chlorophyll *a* values early in the year, during colder water periods, reflect seasonal nutrient regeneration and turnover, while phytoplankton numbers may be low due to low levels of available light. As day cycles lengthen, utilization increases, causing decreases in nutrient concentrations. In summer the values remain low due to utilization. In 1978, only in May did nitrate and phosphate approach levels reported to be limiting in culture (< 2 µg-at P/l and <1.5 µg-at N/l) (Parsons and Takahashi, 1974). While some slowing of growth has occurred, it does not appear that nutrient levels were a major factor in limiting phytoplankton growth except for short periods during the year; this parameter of primary production does not appear to have changed significantly from 1974-1978.

Some evidence of the effects of a breakdown in the TITP plant in late June to August 1978, appears in nutrient and chlorophyll data. Ammonia and phosphate showed anomalously high levels in July, and nitrites also showed a possibly related peak in August, reflecting concentrations directly at the outfall station (A7) or nearby; these levels dropped immediately to previous levels (Figures 5 and 6). Chlorophyll *a* biomass, however, at stations near the outfall (A7 and A4), decreased in July, suggesting a toxic effect on the phytoplankton, presumably from the wastes and control substances used. Data for the harbor as a whole suggest that chlorophyll biomass has remained relatively stable in 1977 and 1978.

Chlorophyll *a* values typically show a spring bloom in response to the above factors, but data for 1978 did not show this. One possible explanation is that phytoplankton blooms can sometimes be extremely short in duration, as zooplankton grazing can reduce phytoplankton stocks by orders of magnitude in a few days (Fleming, 1939). It is therefore possible to miss a peak entirely when sampling only once a month. Nitrogen concentrations decreased rapidly during the spring as if utilization were in fact occurring. Therefore, it is possible that the usual spring bloom occurred as in 1976 and 1977, but was underestimated due to the sampling program.

Uptake rates were rather low in 1978, therefore assimilation ratios are low as well. This may indicate a low C:N ratio in the harbor in 1978, perhaps as a result of a change in carbonate equilibrium.

In comparing chlorophyll values for 1976-78 from Harbors Environmental Projects data (this volume, section IIC), total chlorophyll *a* biomass values were quite similar for 1977 and 1978 (35 ± 1 mg Chl $a/m^3/yr$). 1976 values were higher (40 mg Chl $a/m^3/yr$), but not markedly. The seasonal pattern is essentially the same for all three years. Further, the seasonal pattern inside the harbor parallels that seen at station A1 outside the harbor proper, indicating, as stated in section IIIC of this volume, that causative conditions are not unique to the harbor, and implicating considerable seasonal influence from the basic character of waters resident along the coast. The effects of natural yearly oscillations cannot be assessed from this short-term period; nevertheless, all indicators except carbon uptake indicate that chlorophyll biomass in the harbor has not changed significantly over the three year period. This suggests that secondary treatment of cannery effluents has had little overall effect, and it is surprising that the institution of secondary treatment of harbor wastes begun in the spring of 1977 has not had a greater effect. Aside from considerations of phytoplankton species composition and annual fluctuations in water mass characteristics, the total phytoplankton food supply for larval fishes in the harbor has not apparently become a limiting factor.

Fish Populations

Adult populations of fish in the harbor have shown a decreasing trend since 1974. Two important species, *Genyonemus lineatus* (white croaker) and *Engraulis mordax* (Northern anchovy), have shown the most dramatic drops and thus heavily influence fish trawl data (Stephens, 1974; Section IIA, this volume). For the numerically dominant fish in the harbor, *Genyonemus*, a major factor in its decline is the removal of particulate cannery wastes. In 1974, trawls in and about the cannery outfall area captured > 700 fish/trawl, with a preponderance of *Genyonemus*. During the summer of 1973 Stephens captured more than 25,000 juveniles in the outfall area. After introduction of DAF treatment to coagulate wastes, fish populations around the outfall dropped to around 160 fish/trawl in 1975 and 88 fish/trawl in 1976. In 1978 around the outfall area, the number of fish per trawl was 125, increasing in July to 993 fish/trawl, exceeding 1974 values. This increase probably resulted from the breakdown in the TITP plant, releasing sewage into the area and causing a rise in BOD and suspended solids of 10 and 30 times, respectively. This evidence, with trawl data before and after DAF installation, as well as the report by Reish and Ware (1976) on the feeding habits of *Genyonemus*, show that, at least in part, the decrease in adult fish populations can be attributed to a reduction in available food resources. The DAF treatment removed available organic nutrients that were previously discharged into the harbor by the cannery (Section IIE, this volume) and probably had a far greater impact than secondary waste treatment. *Genyonemus* is an omnivore (Reish and Ware, 1976) and consumes large numbers of benthic polychaete worms. A drop in organic nutrients and increased predation pressure on polychaete populations, affecting both abundance and species composition, would greatly reduce the nutrient source available to bottom-feeding fish.

The Northern anchovy population (*Engraulis mordax*) has been declining in the Southern California Bight area for the past five years. Acoustical surveys show a 1973 peak of 1.8 -2.0 x 10^6 T, less than 5 x 10^5 T in 1978 and 3 x 10^5 T in 1979 (Frey, personal communication), showing a six-fold decrease in five years. In the harbor, though, based upon the data of Stephens *et al.* (1974) and Harbors Environmental Projects (this volume, Section IIA), anchovy biomass has been reduced a thousand-fold. Possibly the installation of DAF treatment by the fish canneries has also influenced the decline of *Engraulis* in the harbor. The harbor has not had a dinoflagellate bloom in recent years (Morey-Gaines, personal communications) which constitutes a large part of the larval anchovy's diet (Lasker, 1975). The reasons for this are not clear but may relate to temperature, or to bacterial populations decreases (Oguri, Soule, Juge and Abbott, Red Tide Conference, 1975). Bacterial populations dropped 30-fold following TITP conversion to secondary treatment (Section III, this volume), but there are no comparable data for previous years.

While adult populations of *Genyonemus* and *Engraulis* have been greatly reduced, other species have more nearly maintained their population levels since 1975. This suggests both that waste treatment can have species-specific effects and that independent factors can operate in a complex system that may confuse interpretation of cause-effect relationships.

Larval Abundance

Based on large numbers of juveniles encountered by Stephens (1974) in the summer of 1973 it is reasonable to assume that large numbers of eggs and larvae were spawned in the preceding couple of years. However, the previous ichthyoplankton survey did not show the expected high numbers of larvae or eggs during the early months of 1973 and 1974 when *Genyonemus* spawns (AHF, 1976). In contrast, in January and February, 1978, this study found numbers of eggs and larvae that peaked at values in the hundreds per cubic meter, which are extraordinarily high (Figure 7) and indicate a highly productive area. In comparison, values for a recreational harbor in Santa Monica Bay (King Harbor) showed larval densities of 44/m^3 at the richest station (McGowen, 1978).

A possible factor contributing to this abundance is that several genera of the sciaenids (*Bairdiella*, *Umbrina* and

Seriphus) exhibit cannibalistic or predatory behavior on eggs and larvae (Maxwell, 1975); the flatfish *Citharichthys* has been known to have fish eggs in its guts (Reish and Ware, 1976). A considerable decrease in the adult fish population between 1973 and 1978 could affect predation levels and thus would increase the number of larvae and eggs in the water column.

Another factor that must be considered is the sampling method. The original survey consisted in horizontal tows at approximately 4 m below the surface. In the harbor, a chlorophyll maximum layer was found around 3 m (Section IIIC, this volume). Lasker's (1975) work with anchovy larvae demonstrated larval and egg stratification in and above the chlorophyll maximum. He found that larvae without pigment in their eyes (therefore nonfunctional) were found in high abundance above the chlorophyll maximum layer, while sighted larvae were found predominantly in the chlorophyll maximum layer, and abundance above the layer exceeded that below by a factor of ten. Eggs were stratified also, with a high abundance in and above the layer. Furthermore, anchovy larvae with pigmented eyes show significant net avoidance (P. Smith, 1972). Other larvae could stratify in a similar manner. Over 60% of sciaenid larvae from the oblique bongo tows, sampling the whole of the water column, were without eye pigmentation, indicating successful sampling of upper layers. While no evidence concerning pigmentation is available from the earlier study, it is likely that sampling at 4 m would result in a significant decrease in the number of eggs and larvae captured relative to the actual population. Although the magnitude of this decrease cannot be accurately estimated it is probably not sufficiently great to account for the discrepancy in abundances between 1974 and 1978. Possibly a ten-fold higher abundance in 1978 is a more reasonable estimate.

The number of species of fish larvae collected each month in 1978 ranged from 5-18 with a baseline around eight and two peak periods in spring and fall ($\bar{x} = 11.6$). Data for adult fish species in the same area show a range of 0-15 and mean around 7 for 1974-1978 (Environmental Quality Analysts/Marine Biological Consultants, 1978), and in another study (Stephens, 1974), a range of 1-11 and a mean of 6. This higher number of species in the ichthyoplankton collected in 1978 alone may reflect a higher diversity than in earlier years, although possibly the difference in sampling methods could allow a different representation of species in the catches.

It is tempting to speculate that these high abundances of 1978 eggs and larvae will result in increases in future adult populations, but further investigation is needed in order to predict the fate of the high number of eggs and larvae (Hempel, 1965). Without additional sampling employing collection of settled larvae, there are no direct means of determining success of recruitment. It has been demonstrated (Lasker, 1975; O'Connell and Raymond, 1970) that first-feeding anchovy larvae require high concentrations of food particles of a certain size. Cell size and abundance cannot be extrapolated directly from chlorophyll concentrations alone. Cell size distribution depends on the presence of suitable species and on their succession in the phytoplankton. Limited information concerning species composition and size distributions within the phytoplankton is available (Section IIIC, this volume). Generally, red tide blooms were lacking in 1978, and without high concentrations of dinoflagellates recruitment of anchovy larvae cannot be expected to have a high rate of success. The data are insufficient to predict future adult population abundances.

CONCLUSIONS

Secondary treatment has not significantly altered nutrient conditions, which seem to follow seasonal trends that occur throughout the Southern California Bight. This change also has not significantly altered phytoplankton biomass, which follows the patterns of abiotic factors (nutrients, temperature, salinity and light levels) that are influenced by offshore events. Nevertheless, adult populations of fish in the harbor have been declining since dissolved air flotation (DAF) treatment was initiated in 1975. Previous studies show that the dominant adult fish species *Genyonemus* utilized the outfall area for foraging on suspended cannery wastes, and also fed on numerous benthic worms in the enhanced area of the outer harbor. The number of adult fish captured per trawl increased by an order of magnitude for a brief period in 1978 coincident with a TITP malfunction, when particulate sewage and industrial wastes were discharged into the harbor at the outfall. The fish numbers then declined after full recovery of the treatment plant. High nutrient values occurred during the breakdown, but chlorophyll biomass was slightly reduced. Chlorination was also going on at that time.

The present study found higher counts of eggs and larvae than were found in an earlier study; this is probably due to reduced predation by adult fish and to more efficient sampling methods. Larval species demonstrated discrete distributions within the harbor according to habitat and food resource. Success of recruitment of larvae cannot be predicted on the basis of egg and larvae census alone, as was demonstrated by the huge numbers of anchovy larvae offshore in 1975 which failed to recruit for unknown reasons. The result has been a 4-fold drop in spawning biomass off California by 1979. Therefore, the contribution of these larvae to future adult populations remains in the realm of speculation.

LITERATURE CITED See Section VI

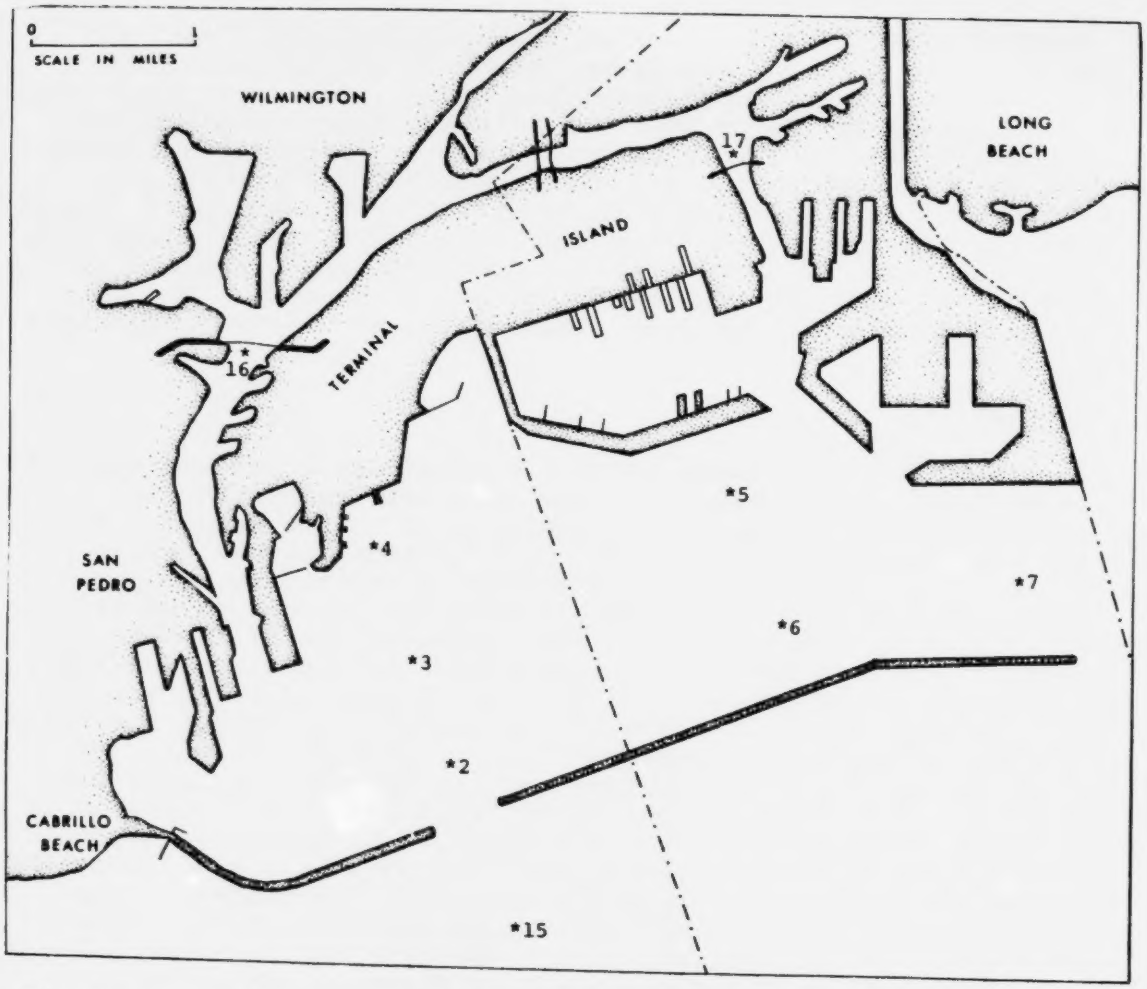

Figure 1. Ichthyoplankton trawl stations, 1978. Station 21 is approximately 2 miles off the breakwater.

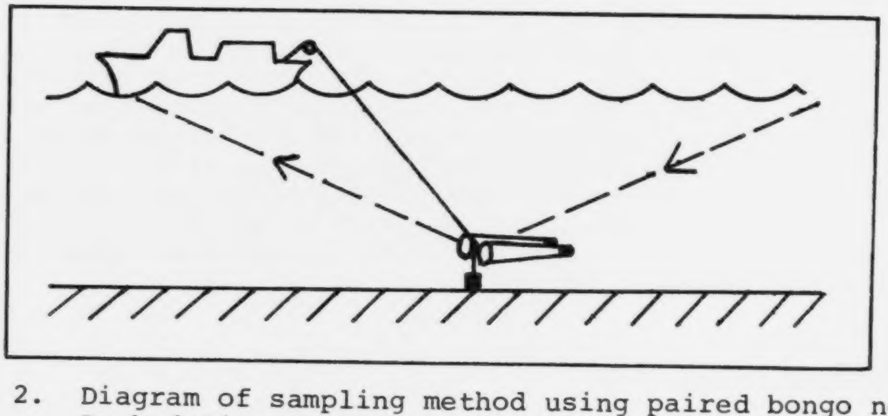

Figure 2. Diagram of sampling method using paired bongo nets. Dashed line represents complete path towed through sampling location.

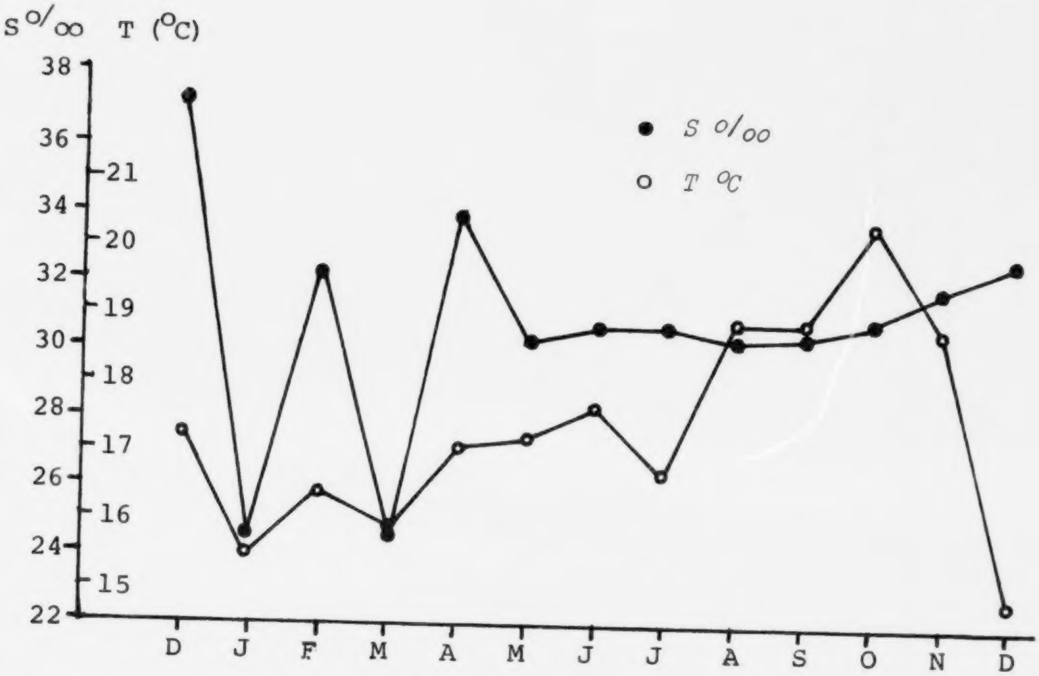

Figure 3. Mean monthly temperature and salinity values recorded in 1978. Monthly averages represent data collected at selected harbor stations on sampling dates most closely correlated to ichthyoplankton trawl dates.

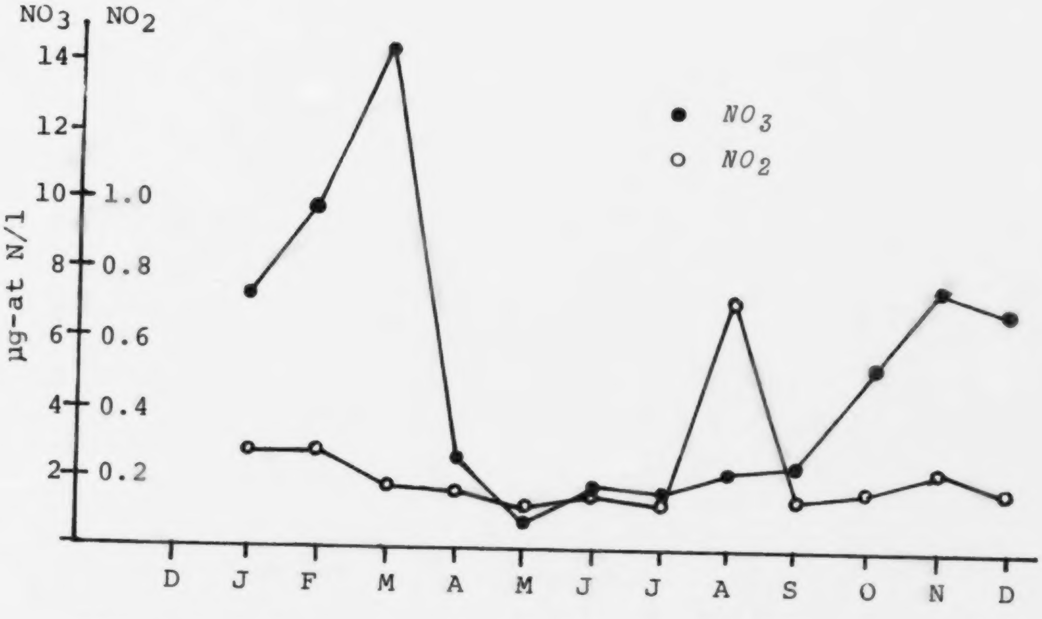

Figure 4. Mean monthly NO_3 and NO_2 nitrogen levels in μg-at/l for 1978. Monthly averages represent data collected at selected harbor stations on sampling dates most closely correlated to ichthyoplankton trawl dates.

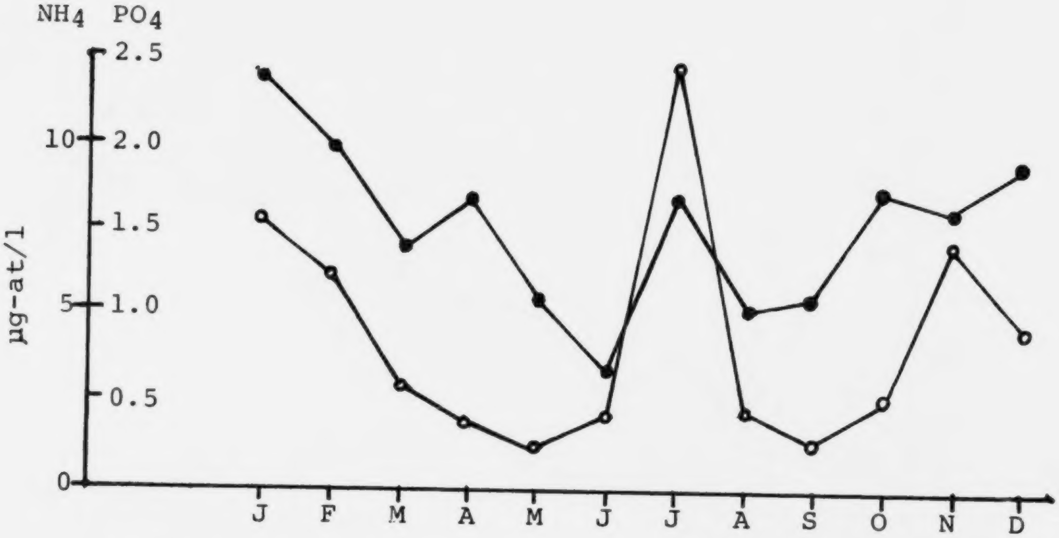

Figure 5. Mean monthly ammonia nitrogen levels (o) and PO_4 phosphate levels (●) in µg-at/l for 1978. Monthly averages represent data collected at selected harbor stations on sampling dates most closely correlated to ichthyoplankton trawl dates.

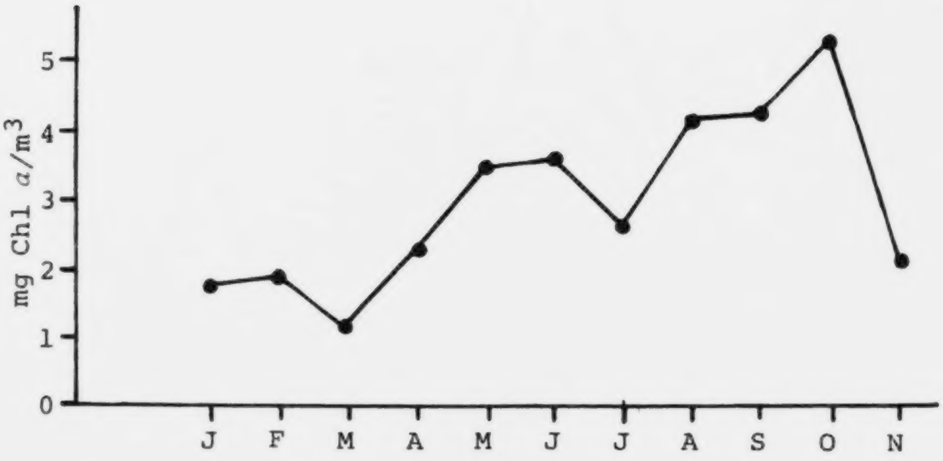

Figure 6. Mean monthly chlorophyll *a* levels in mg/m^3 for 1978. Monthly averages represent data collected at selected harbor stations on sampling dates most closely correlated to ichthyoplankton trawl dates.

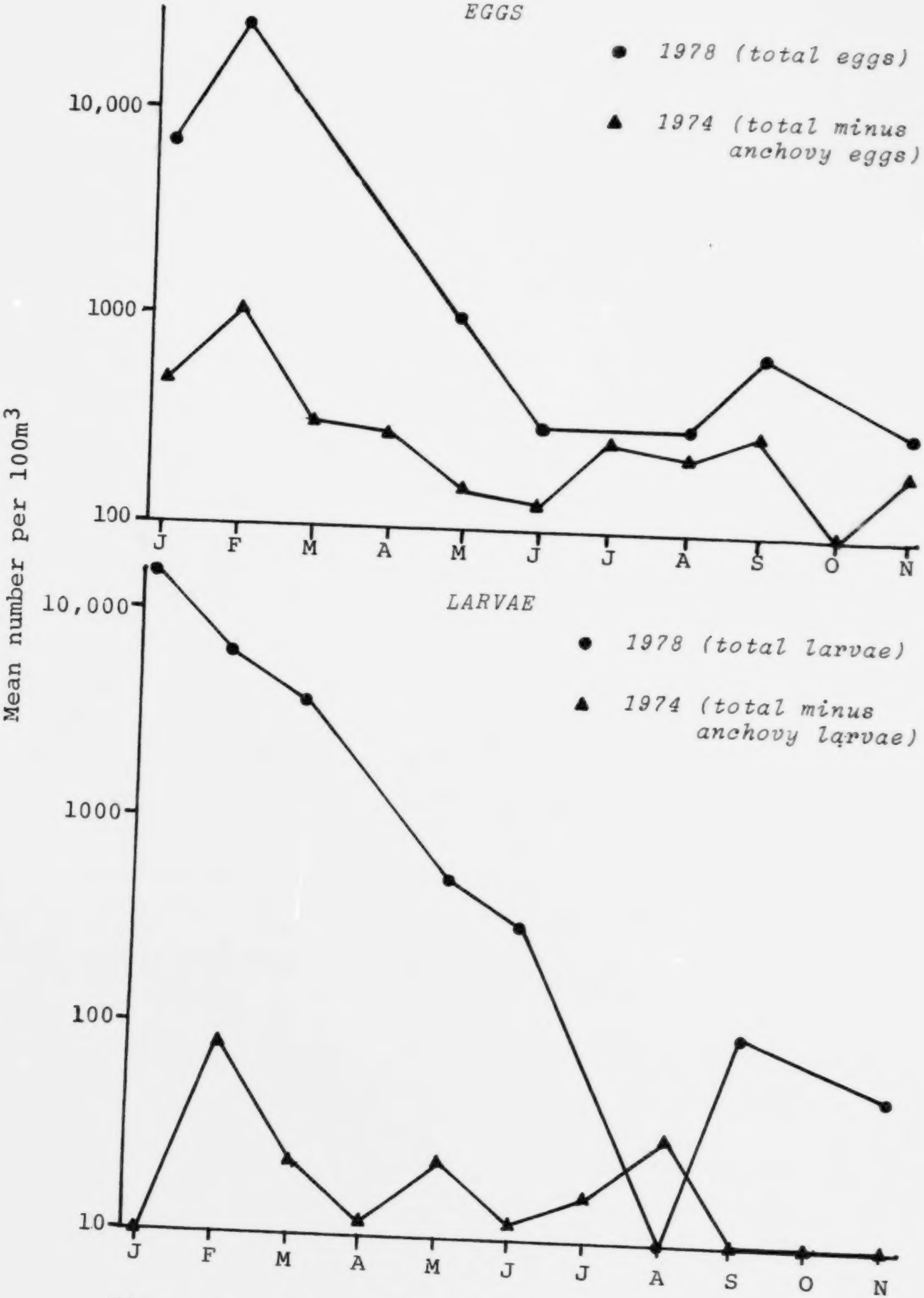

Figure 7. Mean number of fish eggs and larvae collected per m^3 of water filtered for Los Angeles Harbor and in 1974 from San Pedro Bay. Latter values represent total numbers excepting anchovy eggs and larvae.

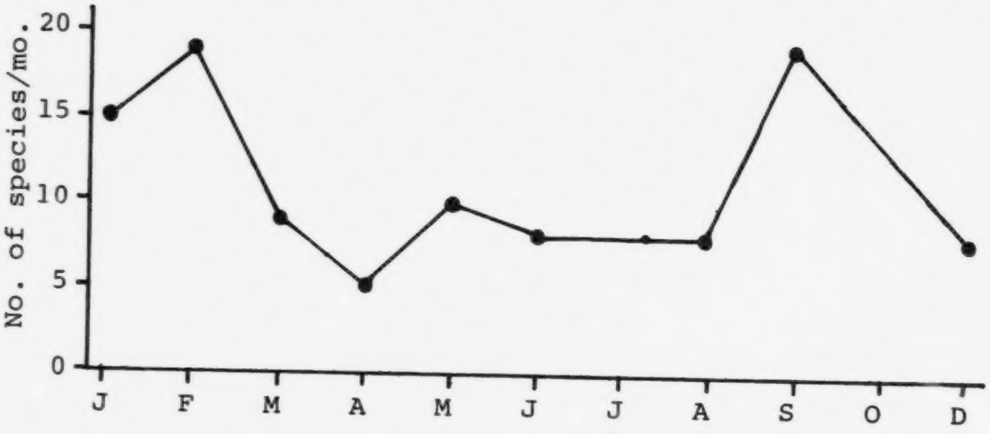

Figure 8. Number of species of fish larvae collected during 1978.

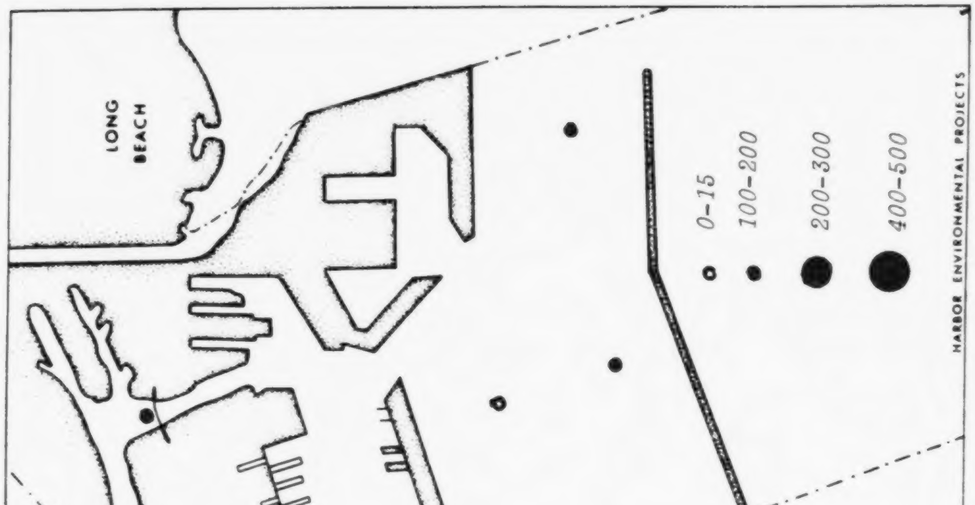

Figure 9. Distribution of total number of larvae/m^3 in the Los Angeles-Long Beach Harbors in 1978.

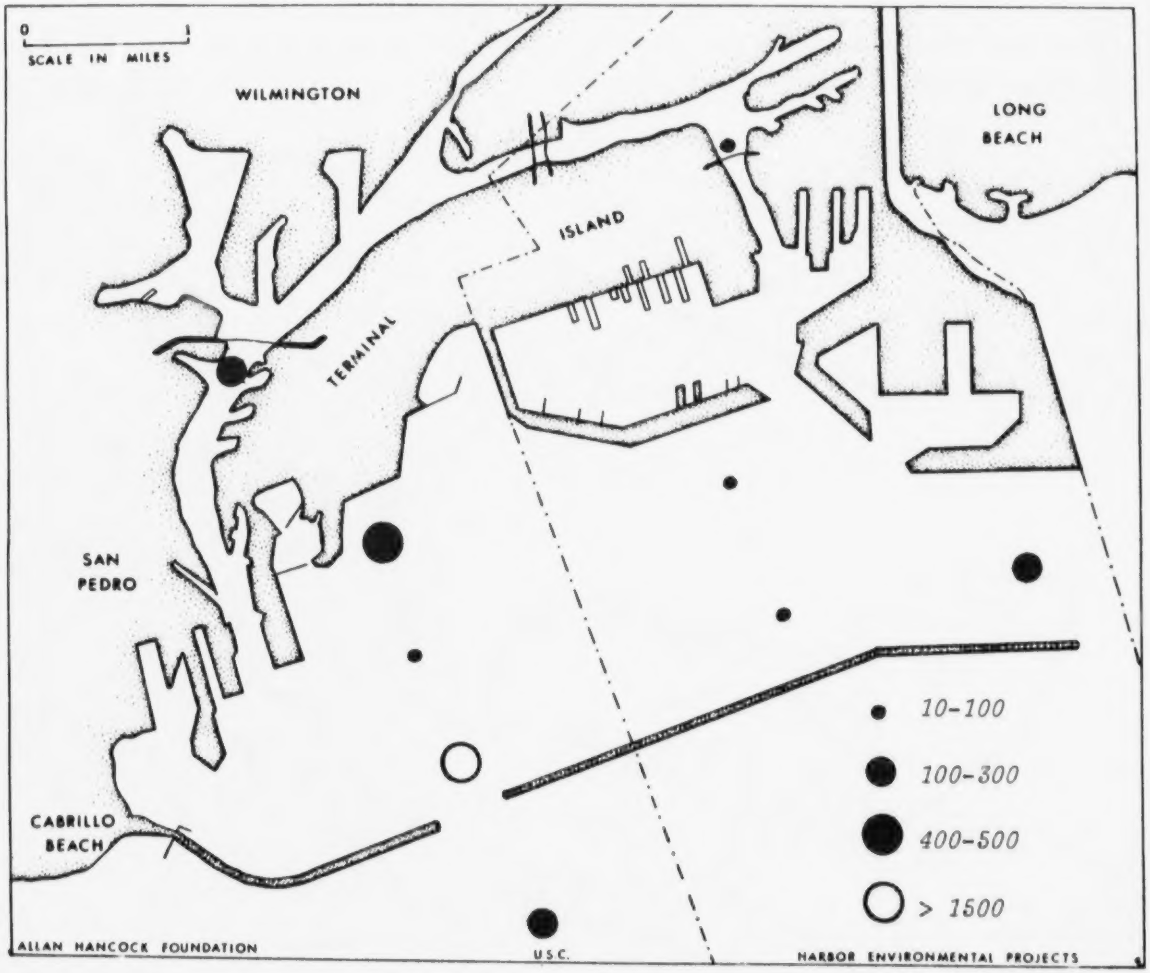

Figure 10. Distribution of total number of eggs/m^3 in the Los Angeles-Long Beach Harbors in 1978.

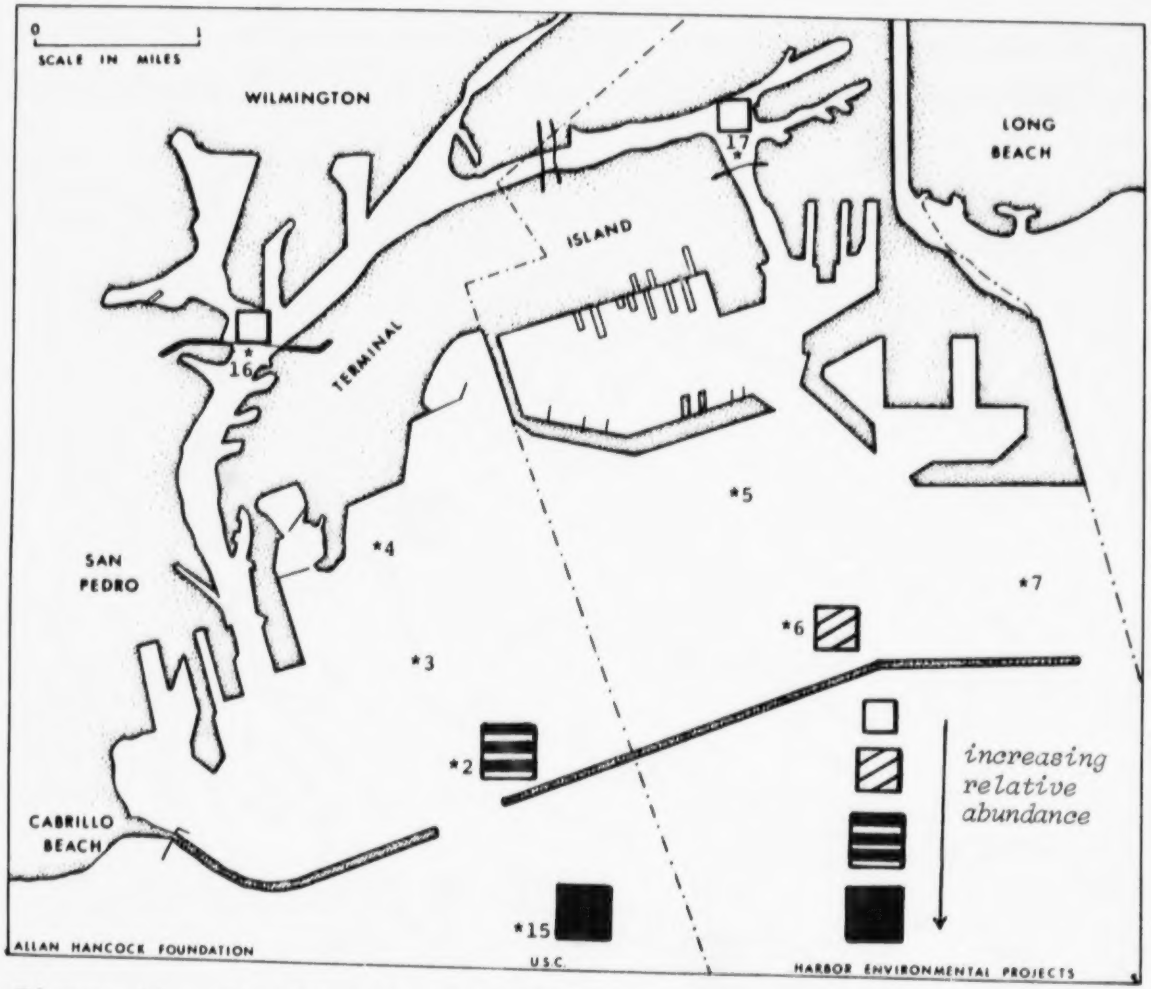

Figure 11. Stations showing highest abundances of engraulid larvae.

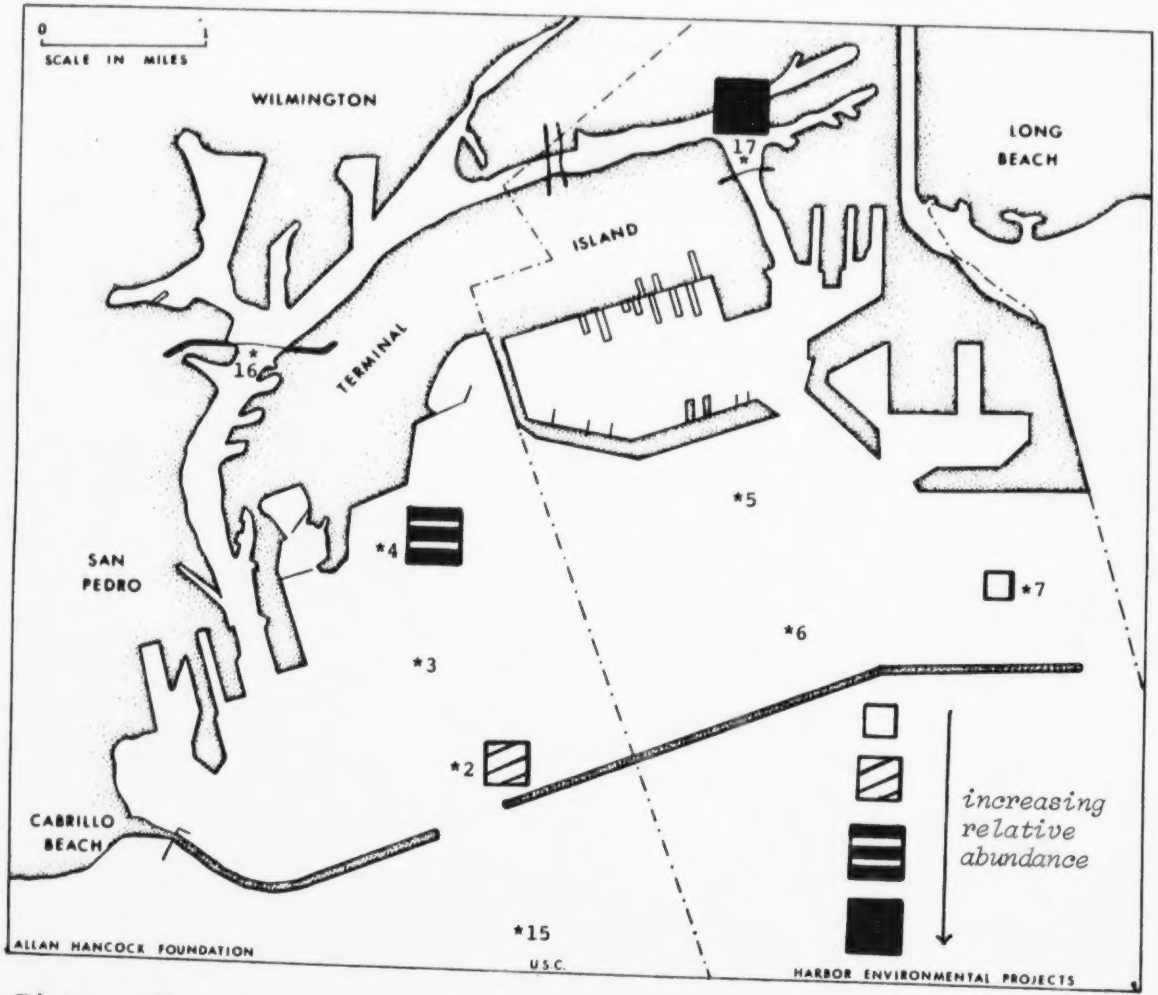

Figure 12. Stations showing highest abundances of *Genyonemus lineatus* larvae.

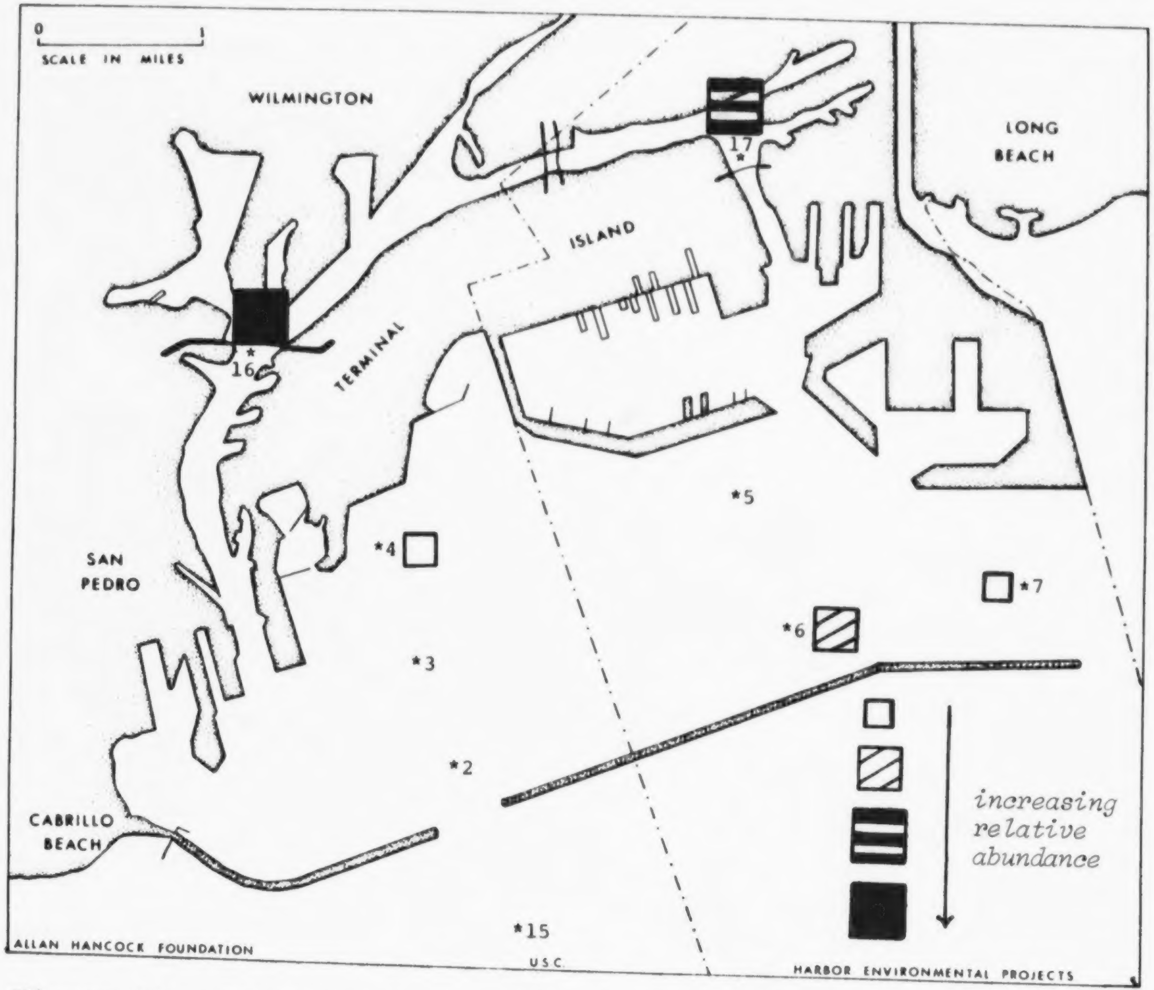

Figure 13. Stations showing highest abundances of gobiid larvae.

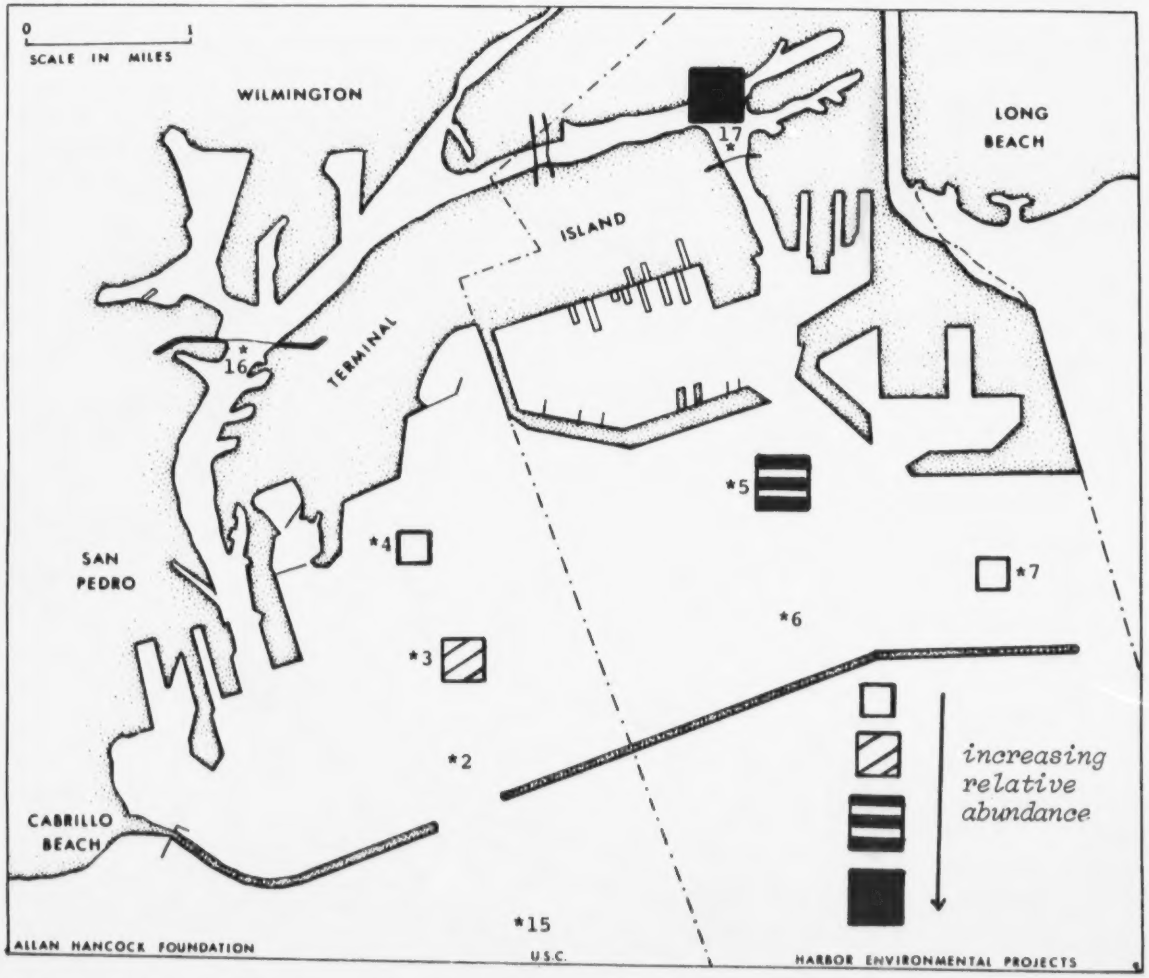

Figure 14. Stations showing highest abundances of *Hypsoblennius* sp. larvae.

Table 1. Monthly sampling regime in Los Angeles-Long Beach Harbors in 1978 according to stations and to samling and quantification methods.

St.	J	F	M	A	M	J	J	A	S	O	N
2	B*	B*	B	B/So	B*/So	B*/So		B/S*	B*/S*		B/S*
3				B/So	B*/So	B*/So		B/S*	B*/S*		B/S*
4	B*	B*	B	B/So	B*/So	B*/So		B/S*	B/S*		B/S*
5				B/So	B*/So	B*/So		B/S*	B/S*		B/S*
6	B*	B	B	B/So	B*/So	B*/So		B/S*	B/S*		B/S*
7	B*	B	B	B/So	B*/So	B*/So		B/S*	B/S*		B/S*
15	B*	B*	B	B/So	B*/So	B/So		B/S*	B/S*		B/S*
16	B*	B*	B	B/So	B*/So	B*/So		B/S*	B/S*		B/S*
17	B*	B*	B*								
21	B*	B*	B								

day (J–M) night (A–N)

B = bongo nets
S = surface tows
o = identified but not quantified
* = identified and quantified

Table 2. Taxonomic classification of larvae and eggs collected in Los Angeles-Long Beach Harbors in 1978.

- Atherinidae
    - unidentified
- Blenniidae
    - *Hypsoblennius*
- Bothidae
    - *Paralichthys/Xystreurys*
    - *Citharichthys*
- Carangidae
    - *Seriola/Trachurus*
- Clinidae
    - unidentified
- Cottidae
    - *Clinocottus* type
    - *Scorpaenichthys marmoratus*
    - unidentified
- Cynoglossidae
    - *Symphurus atricauda*
- Engraulididae
    - *Engraulis mordax**
- Gobiesocidae
    - *Gobiesox rhessodon?*
- Gobiidae
    - unidentified
- Labridae
    - *Oxyjulis californica*
- Merlucciidae
    - *Merluccius productus*
- Myctophidae
    - *Stenobrachius leucopsarus*
    - *Triphoturus mexicanus*
- Ophidiidae
    - *? Chilara taylori*
    - *? Otophidium scrippsi*
- Pleuronectidae
    - *Hypsopsetta guttulata*
    - *Pleuronichthys ritteri*
    - *Pleuronichthys verticalis*
- Pomacentridae
    - *Chromis punctipinnis*
    - *Hypsypops rubicundus*
- Sciaenidae
    - *Cheilotrema saturnum*
    - *Genyonemus lineatus*
    - *Seriphus politus*
- Scorpaenidae
    - *Sebastes* I
    - *Sebastes* II
- Serranidae
    - *Paralabrax*
- Sphyraenidae
    - *Sphyraena argentea*
- Stromateidae
    - *Peprilus simillimus*
- Synodontidae
    - *Synodus lucioceps*
- Unidentified
- Yolk sac larvae

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* possibly other Engraulids included

Table 3. Abundance of eggs and larvae from Los Angeles-Long Beach Harbors in 1978.

Taxon	# Captured	#/100m^3/yr	*f*	# of months occurred
Genyonemus lineatus	5001	108,413	15	4
Engraulididae	2567	41,034	40	9
Gobiidae	665	9,243	39	6
Hypsoblennius	502	2,930	38	9
Seriphus politus	92	203	10	3
Symphurus atricauda	73	178	5	1
Sebastes I	54	888	11	3
Stenobrachius leucopsarus	34	596	6	2
Paralabrax	33	76	4	2
Paralichthys/Xystreurys	27	402	9	4
Pleuronichthys ritteri	23	357	8	4
Oxyjulis californica	23	56	1	1
Citharichthys	19	176	9	5
Sphyraena argentea	18	44	3	2
Pleuronichthys verticalis	18	309	10	4
Gobiesox rhessodon?	15	174	9	3
Clinidae	11	124	10	6
Unidentified	11	98	6	2
Yolk sac	7	14	5	2
Atherinidae	7	--	4	1
Cottidae	6	99	5	2
Chromis punctipinnis	6	13	4	1
Cheilotrema saturnum	6	13	3	1
Peprilus simillimus	5	7	3	2
Hypsypops rubicundus	5	45	4	2
Hypsopsetta guttulata	5	12	4	1
Merluccius productus	4	59	2	1
?Chilara taylori	3	20	2	1
Clinocottus type	3	35	3	2
?Otophidium scrippsi	2	4	2	1
Scorpaenichthys marmoratus	1	10	1	1
Seriola/Trachurus	1	2	1	1
Triphoturus mexicanus	1	10	1	1
Sebastes II	1	16	1	1
Synodus lucioceps	1	--	1	1
Engraulid eggs	316		13	7
Other eggs	22,913		56	8

Table 4. Ranked order of ten most abundant species of fish and larvae.

1978		1974	
LARVAE	ADULTS	LARVAE	ADULTS
Genyonemus lineatus	*Genyonemus lineatus*	Engraulididae	*Genyonemus lineatus*
Engraulididae	*Symphurus atricauda*	*Hypsoblennius*	*Engraulis mordax*
Gobiidae	*Citharichthys stigmaeus*	Sciaenidae	*Symphurus atricauda*
Hypsoblennius	*Seriphus politus*	*Sebastes*	*Citharichthys stigmaeus*
Seriphus politus	*Engraulis mordax*	Gobiidae	*Seriphus politus*
Symphurus atricauda	*Phanerodon furcatus*	Clinidae	*Cymatogaster aggregata*
Sebastes I	*Synodus lucioceps*	*Chromis*	*Phanerodon furcatus*
Stenobrachius	*Paralichthys californicus*	Cottidae	*Porichthys myriaster*
Paralabrax	*Hyperprosopon argenteum*	*Paralabrax*	*Lepidogobius lepidus*
Paralichthys/ Xystreurys	*Sebastes dallii*	*Pleuronichthys verticalis*	*Sebastes miniatus*

MONTHLY STANDING STOCK MEASUREMENTS OF BACTERIOPLANKTON AND PHYTOPLANKTON IN LOS ANGELES HARBOR AND SOUTHERN CALIFORNIA COASTAL WATERS

INTRODUCTION

Current interests concern the relationship between the organic material in sewage and cannery waste effluent discharges into the outer Los Angeles Harbor and the bioenhancement of those waters. Microbes play a key role in the cycling of this material into the food webs which characterize this bioenhancement. A principal role of marine bacteria is the respiration of organic compounds and the consequent regeneration of inorganic nutrients. This activity makes the substrates of primary production available to photosynthetic organisms in the harbor. Marine microbes also initiate an important food web by their assimilation of dissolved organic matter (heterotrophic production). Their cells are then made directly available as food to higher trophic levels. Therefore, to understand these ecologically important members of the marine environment better, a program to determine the monthly standing stock measurements of bacterioplankton and phytoplankton in outer Los Angeles Harbor was undertaken in September 1977. The outer harbor then received fish cannery wastes and secondary effluent from the Terminal Island Treatment Plant (TITP). The cannery effluents were diverted to TITP in October-December 1977, reducing organic nutrient input to the harbor substantially. The effects of this reduction on the bacterioplankton populations was examined during the course of our study.

METHODS

The Acridine Orange Direct Count (AODC) method was used to enumerate bacterioplankton. All water samples were prefiltered through 203 µm mesh zooplankton net after collection in sterile one-liter Niskin water samplers. An appropriate volume of sample (one which yielded approximately 30 bacteria per field when counting) was mixed with 0.5 ml borate buffered formalin (100% formalin saturated with boric acid), 0.5 ml acridine orange solution (50 mg per L stock), and 0.2µ filtered sea water (FSW) yielding a final 5 ml sample which was 5% formalin and 5 mg per L acridine orange. After 3 minutes this mixture was filtered through the appropriate porosity Nuclepore membrane filter or directly onto a wet (with FSW) 0.2µ 25 mm diameter black Sartorius membrane filter (-10 cm Hg vacuum). The filter was then rinsed with 5 ml FSW. A drop of immersion oil, the filter, another drop of oil, and coverslip were placed on a glass slide. This was stored in the dark at 5°C. Ten fields per filter were counted using epifluorescent illumination and 1000x magnification. A mean and standard deviation for the number of bacteria per filter was calculated and this number converted to bacteria per ml ± one standard deviation.

Autofluorescent particles were enumerated from August through December 1978 using an identical slide preparation technique, but without acridine orange staining of the water sample.

Phytoplankton biomass estimates were courtesy of J. SooHoo (Chlorophyll a measurement), T. Sharpe (ATP measurement), and R. Ruse (floristics).

RESULTS AND DISCUSSION

The concentration of live bacteria (cells$\cdot L^{-1}$) was determined by the acridine orange direct count (AODC) method (Daley and Hobbie, 1975), and a biomass estimate ($\mu gC\cdot L^{-1}$) (Ferguson and Rublee, 1976) of the standing stock was made monthly for 1978 for water samples taken 1m below the surface at four stations (A2, A7, A12, B9) in the outer Los Angeles Harbor (Figure 1) and one station (A0) in the coastal waters outside the harbor breakwater (Figure 2). The range over the year for stations in the harbor is 1.6×10^8 cells L^{-1} ($1.3\ \mu gC\cdot L^{-1}$) to 55×10^8 cells$\cdot L^{-1}$ ($42.8\ \mu gC\cdot L^{-1}$), while the annual range in standing stock outside the breakwater is only 1.6×10^8 cells$\cdot L^{-1}$ ($1.3\ \mu gC\cdot L^{-1}$) to 18×10^8 cells$\cdot L^{-1}$ ($14.0\ \mu gC\cdot L^{-1}$). The monthly bacterial standing stock in harbor waters averages 2.5 times that found in coastal waters. All stations show two seasonal blooms of bacteria -- one in late spring and another in early fall.

Phytoplankton biomass was estimated monthly by three independent methods: 1) chlorophyll a measurement (J. SooHoo, personal communication; Figure 3); 2) ATP content of particles (T. Sharpe, personal communication; Figure 4); and 3) direct count of phytoplankton and microzooplankton (R. Ruse, personal communication; Figure 5). Collectively (Figure 6), these data show elevated phytoplankton biomass levels for various stations from April through September, with maxima occurring at different stations in June (A7), July (A2, A12, B9), August (A0), and September (A2, A12, B9). The average annual range is 100 to 1700 $\mu gC\ L^{-1}$ for harbor stations and 100 to 1000 $\mu gC\ L^{-1}$ for station A0. The phytoplankton bloom in late spring coincides with the bacterial bloom at that time. The late summer phytoplankton bloom is followed by an early fall bacterial bloom. The bacterial blooms are correlated with times of increased levels of dissolved and particulate organic materials resulting from: 1) the high phytoplankton standing stock, 1) excretion by phytoplankton, and 3) grazing and excretion by zooplankton.

The natural microbial population was size-fractionated each month by passage of water samples through various porosity Nuclepore membrane filters (Figure 7-15). The harbor water populations are composed of a smaller percentage of small cells averaging 112% ± 27 (1 S.D.) <5μ, 90% ± 21 (1 S.D.) <1μ, and 69% ± 15 (1 S.D.) <0.6μ, when compared with the coastal waters averaging 103% ± 13 (1 S.D.) <5μ, 94% ± 39 (1 S.D.) <1μ, 77%± 40 (1 S.D.) <0.6μ. Conversely, the cells in the harbor environment are generally larger than those found in coastal waters.

The biomass of particles between 0.2 and 1.0μ in size has also been estimated for many of these water samples by measuring the ATP content of this size fraction. ATP biomass estimates (Figure 16) averaged 20 times the AODC bacterial biomass estimates (Figure 17). Among other explanations for this difference are: 1) non-bacterial ATP in this size fraction (in detritus or small pliable eucaryotes capable of passing a 1μm porosity filter), and 2) errors involved in converting to μgC with either technique.

A vertical profile in August, 1978 at station A2 in the harbor (Figure 18) indicated the presence of a subsurface (3m depth) maximum in bacterial standing stock (18.9×10^8 cells$\cdot L^{-1}$ or 14.8 μgC$\cdot L^{-1}$). The water at this depth contained 13% more bacteria than found 1m below the surface and 51% more bacteria than found 1m off the bottom (10m depth).

If one considers a 10 km^2 area containing the four harbor stations (Figure 1) and assumes an average water column depth of 10m and an average bacterial concentration at all depths equal to 80% of those values found at 1m depth, the total bacterial biomass for this part of the harbor can be estimated. This estimate ranges over the year from 110 to 2610 kgC for the volume of water defined.

Orange autofluorescent particles were observed in water samples throughout the year, and quantified in August, October, November and December, 1978 (Figure 19). Little is known about these cells that are thought to be cyanobacteria (J. Sieburth, personal communication). A 1 μm porosity filter allowed 82% of these cells to pass, while none were able to pass a 0.6 μm porosity filter (Figure 20). Their standing stock ranged from 0.2×10^7 cells$\cdot L^{-1}$ (0.09 μgC$\cdot L^{-1}$) to 6.3×10^7 cells$\cdot L^{-1}$) (2.87 μgC$\cdot L^{-1}$) for the four months they were counted. They were of equal concentration in harbor and coastal waters. However, due to the increased bacterial standing stock in the harbor when compared with coastal waters, the biomass of these autofluorescent particles represented 7.0% and 24.8%, respectively, of the bacterial biomass in these two water masses.

Effects of Cannery Effluent Disposal on Bacterioplankton Standing Stocks

In September 1977 the bacterial concentration in outer Los Angeles Harbor waters was 1 to 2 orders of magnitude greater ($237\text{-}1648 \times 10^8$ cells$\cdot L^{-1}$) than the September, 1978 levels ($35\text{-}43 \times 10^8$ cells$\cdot L^{-1}$) (Figure 7) when the discharge of cannery effluents had been discontinued for at least nine months.

Before the discharge was diverted to the Terminal Island Treatment Plant for secondary treatment (TITP), bacterial concentration at the various harbor stations was directly related to proximity to the site of disposal near station A7 (Figure 1). Station A7 contained 1648 χ 10^8 cells$\cdot$L^{-1} while the other three harbor stations (A2, A12, B9) contained 237-308 χ 10^8 cells$\cdot$L^{-1}. Discontinuation of cannery discharge resulted not only in a reduction in total bacterial numbers at all stations, but also in an equalization in the number of bacteria among the four harbor stations. A 27-fold difference in bacterial concentration inside (A7) versus outside (A0) the breakwater in September, 1977 was reduced to a 3-fold difference in September, 1978. It is hypothesized that differences observed between 1977 and 1978 were due to the discontinuation of cannery effluent disposal near station A7. The TITP effluent had already been converted to secondary treatment prior to this study.

Cannery effluent is rich in dissolved organic nutrients, and could support the large population of microheterotrophs found near station A7 in 1977. When discharge was discontinued, nutrients were no longer available to support a large bacterial population. Therefore, when all effluents were converted to secondary treatment in 1978, 1) the total number of bacteria at all stations decreased significantly, 2) the bacterial concentration at A7 was reduced to levels comparable with the other harbor stations, and 3) the large bacterial concentration difference between the harbor stations and station A0 was reduced significantly. Even though data are available for one season only, the magnitude of the change in standing stock of bacterioplankton observed is not believed to be due solely to natural year-to-year fluctuations.

A 10-fold increase in marine bacteria which occurred at all harbor stations from June through October, 1978, originally ascribed to a seasonal pattern related to phytoplankton biomass, warrants reconsideration in light of information recently made available concerning TITP effluent composition and flow-rate. A TITP malfunction from June through August, 1978 resulted in a 10-fold increase in the levels of suspended solids and BOD values in the effluent. This effluent, then, was potentially of sufficient quality and quantity to generate the observed microbial bloom. Thus such changes in the microbial population apparently are excellent indicators of changes occurring in effluent composition.

Note, however, that a parallel change in bacterial numbers was observed at station A0, which is outside the harbor and might be considered as "upstream" of the receiving waters leaving the harbor. Therefore, a seasonal bloom of bacteria and the TITP malfunction may have occurred simultaneously, jointly affecting microbial biomass in the harbor, or tidal flushing may distribute the nutrients outside the harbor when levels are high enough in the effluent. A second year of monitoring microbial populations in the harbor may allow one to distinguish between these alternatives.

LITERATURE CITED See Section VI

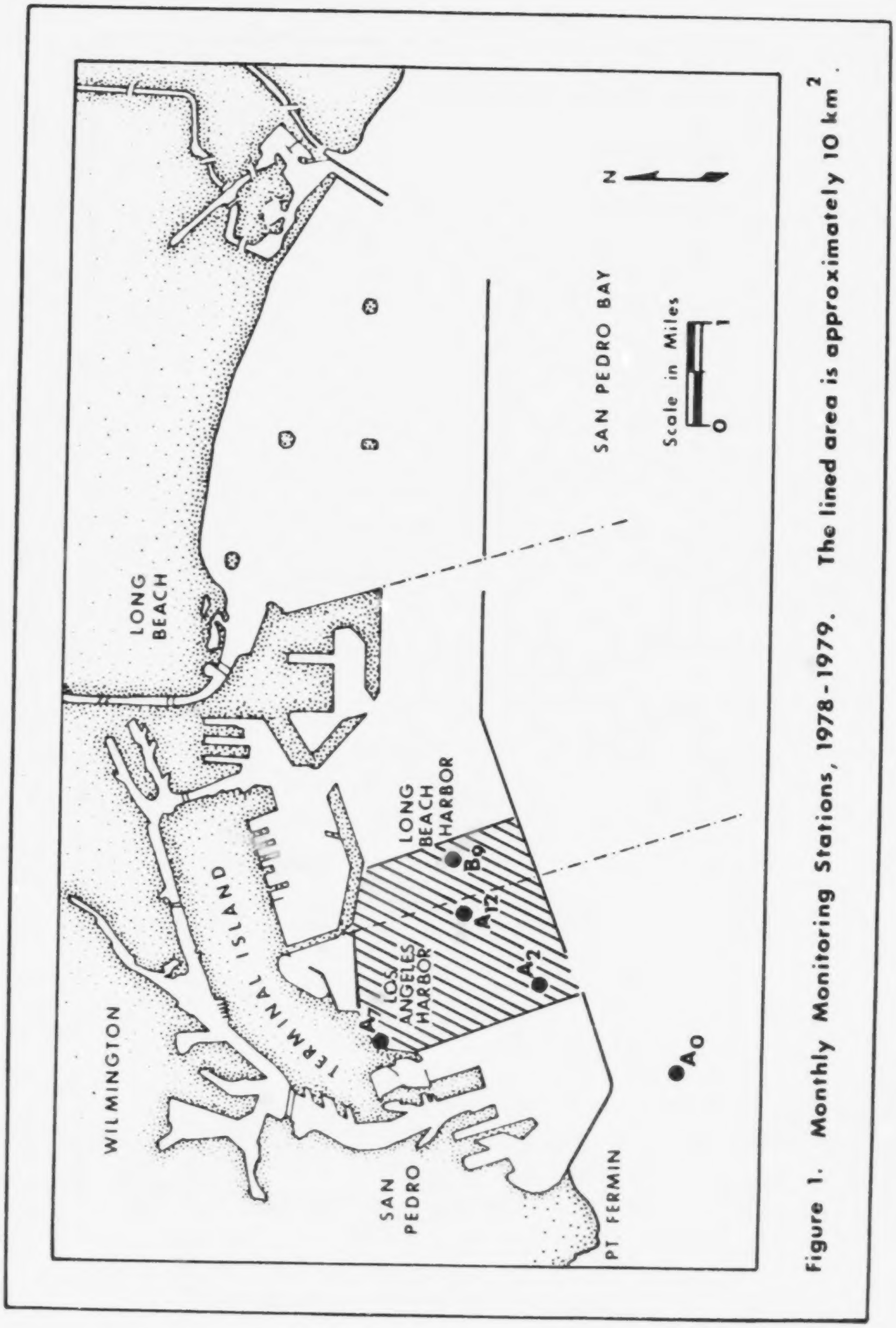


Figure 1. Monthly Monitoring Stations, 1978-1979. The lined area is approximately 10 km^2.

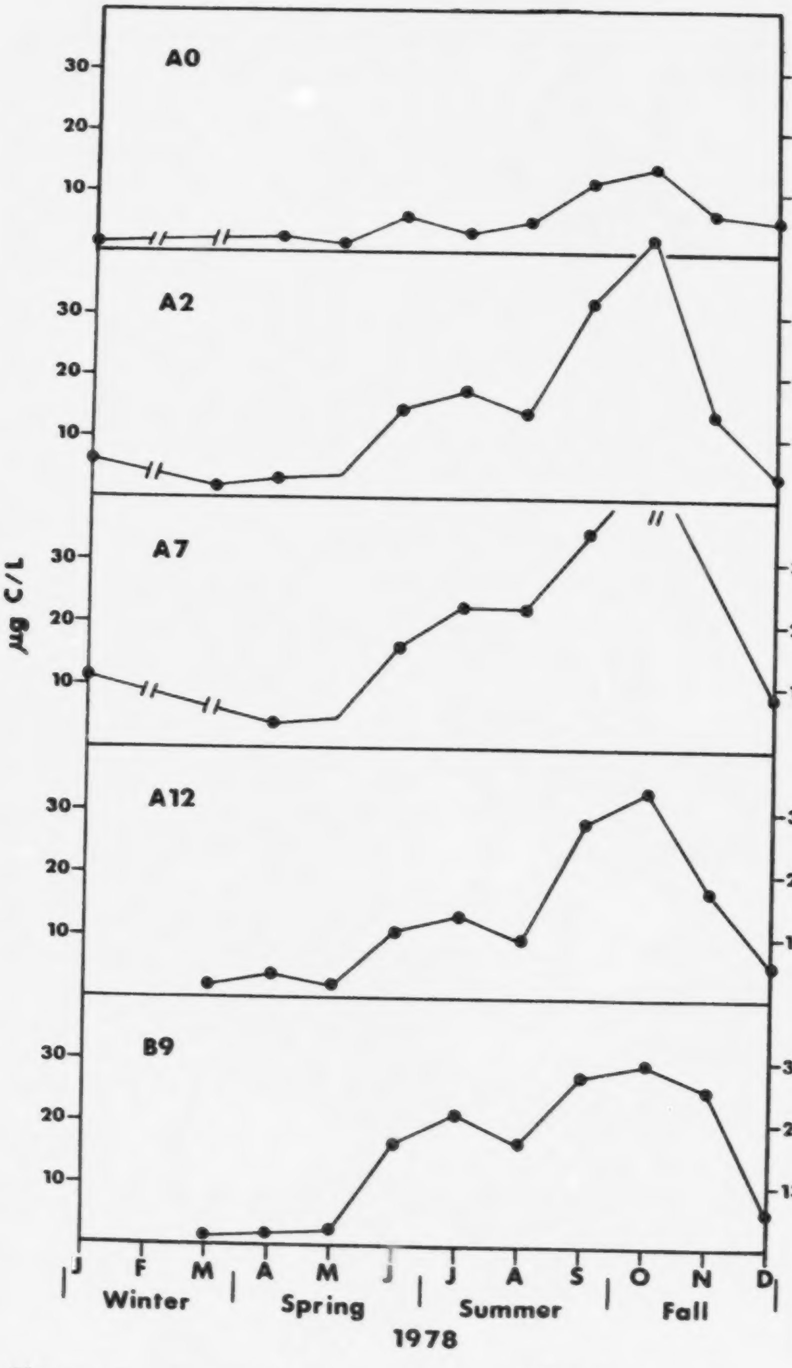


Figure 2. Bacterial Concentration (10^8 Cells/L) and Biomass (μg C/L) from Total AODC

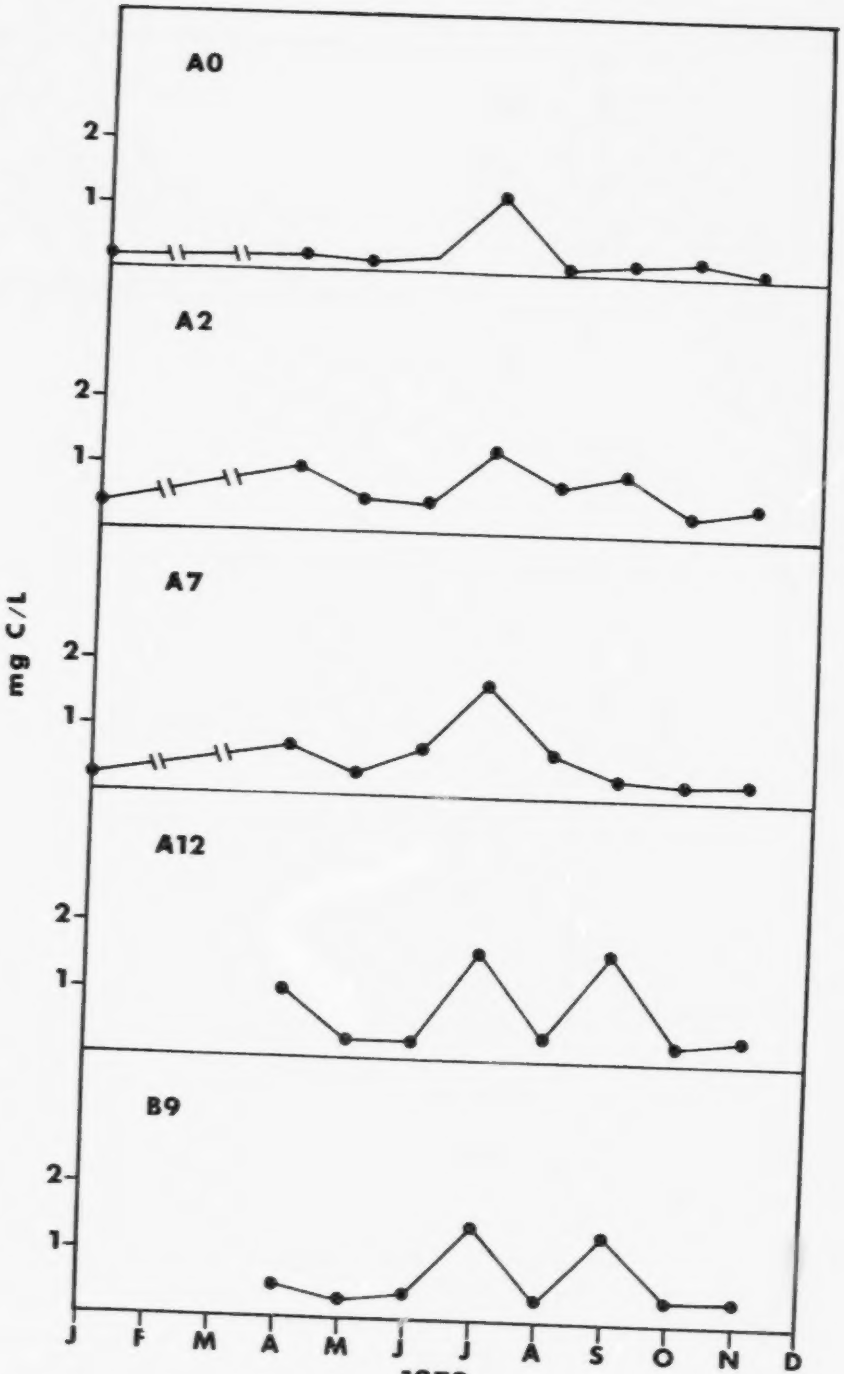


Figure 3. Biomass (mg C/L) from Chlorophyll a x 75 Measurements

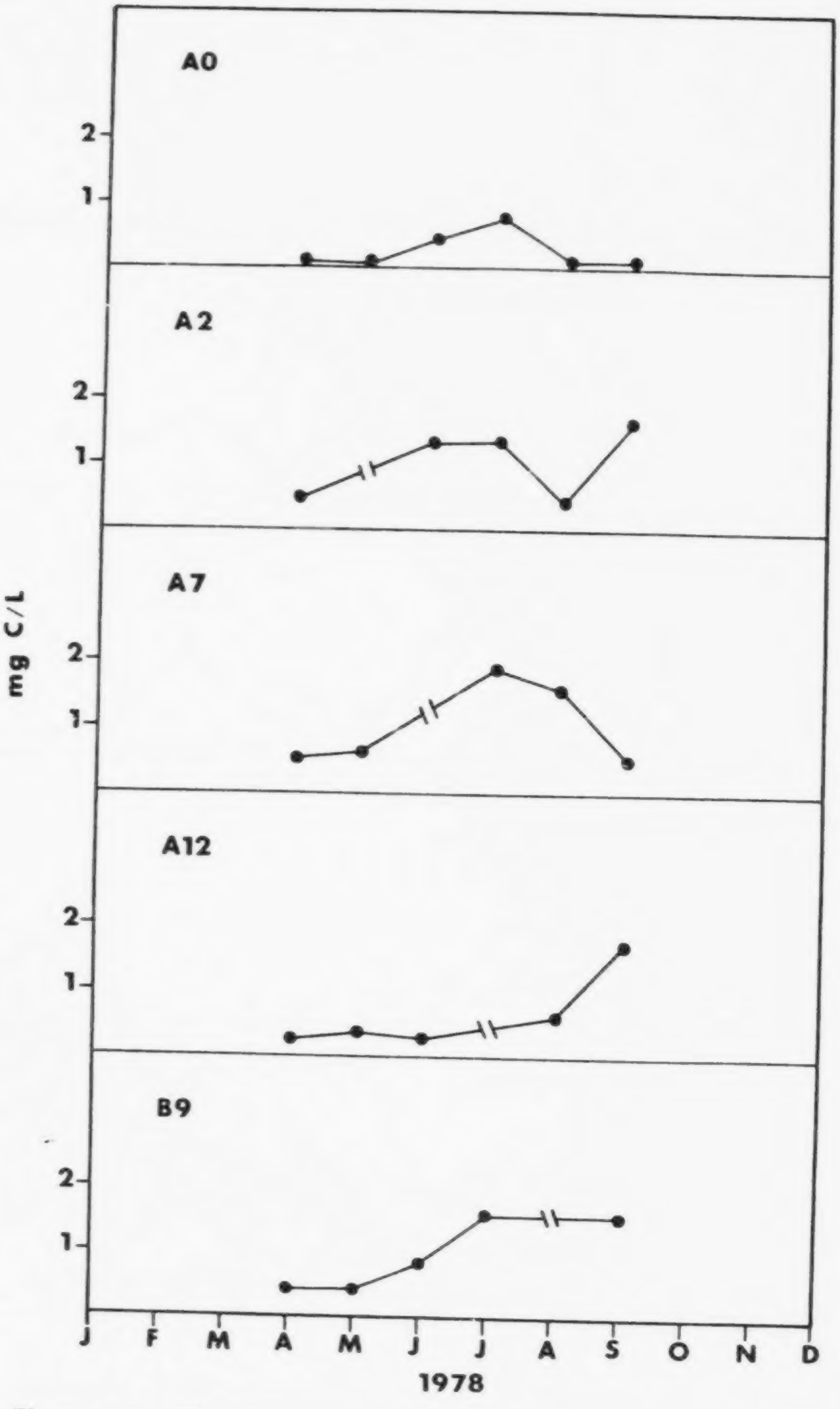


Figure 4. Biomass (mg C/L) from ATP Analysis >1μ

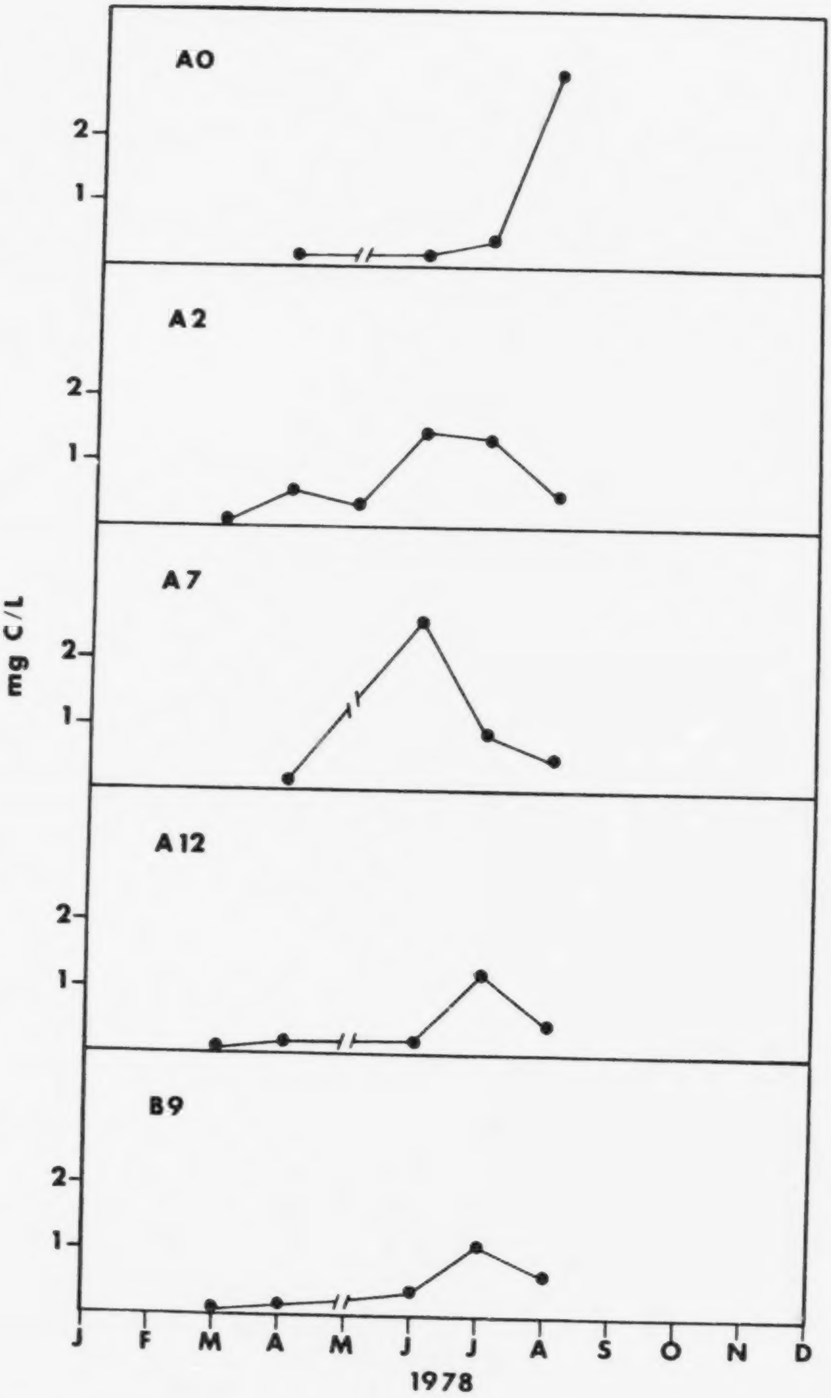


FIGURE 5. BIOMASS (MG C/L) FROM PHYTOPLANKTON AND MICROZOOPLANKTON COUNTING

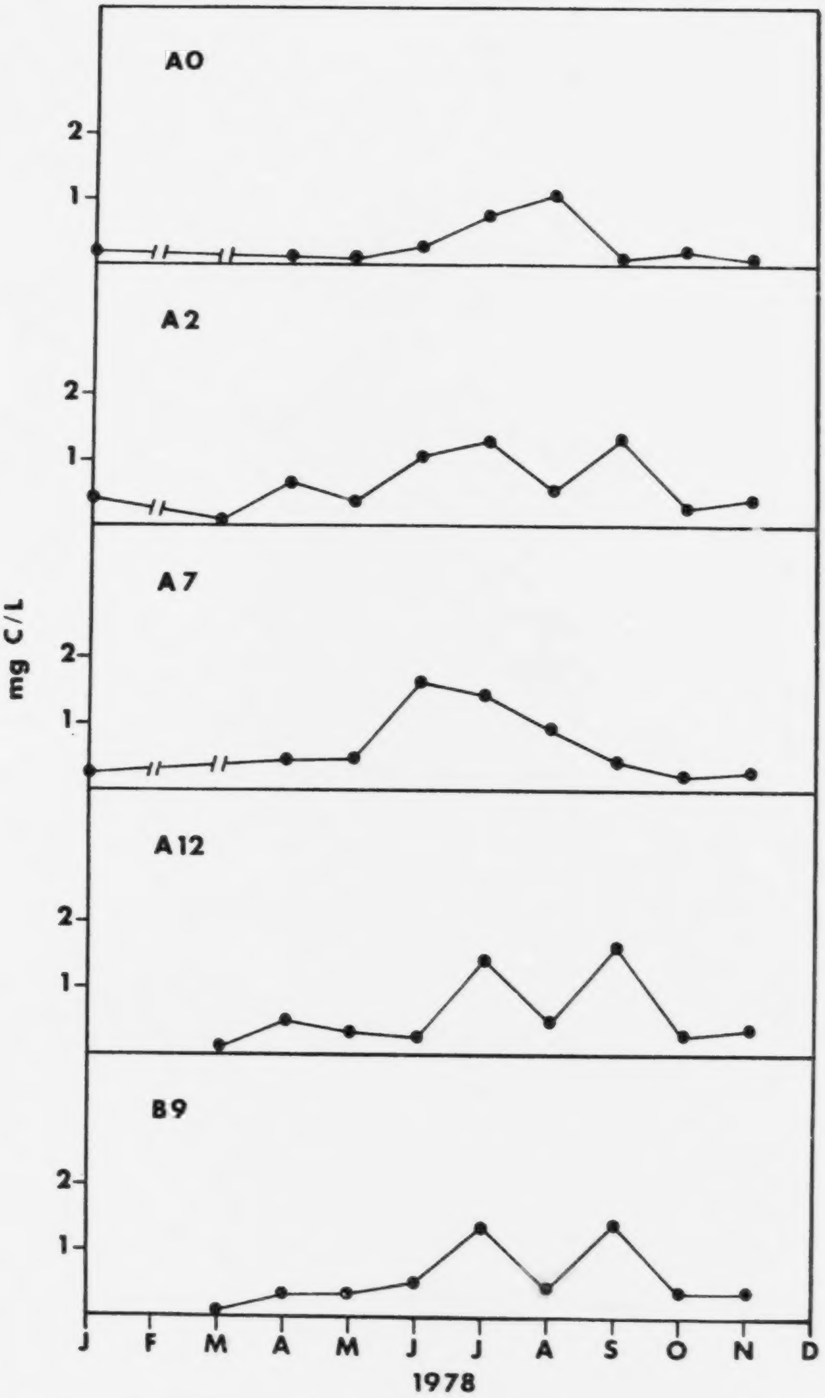


Figure 6. Biomass (mg C/L) Composite of Three Phytoplankton Methods

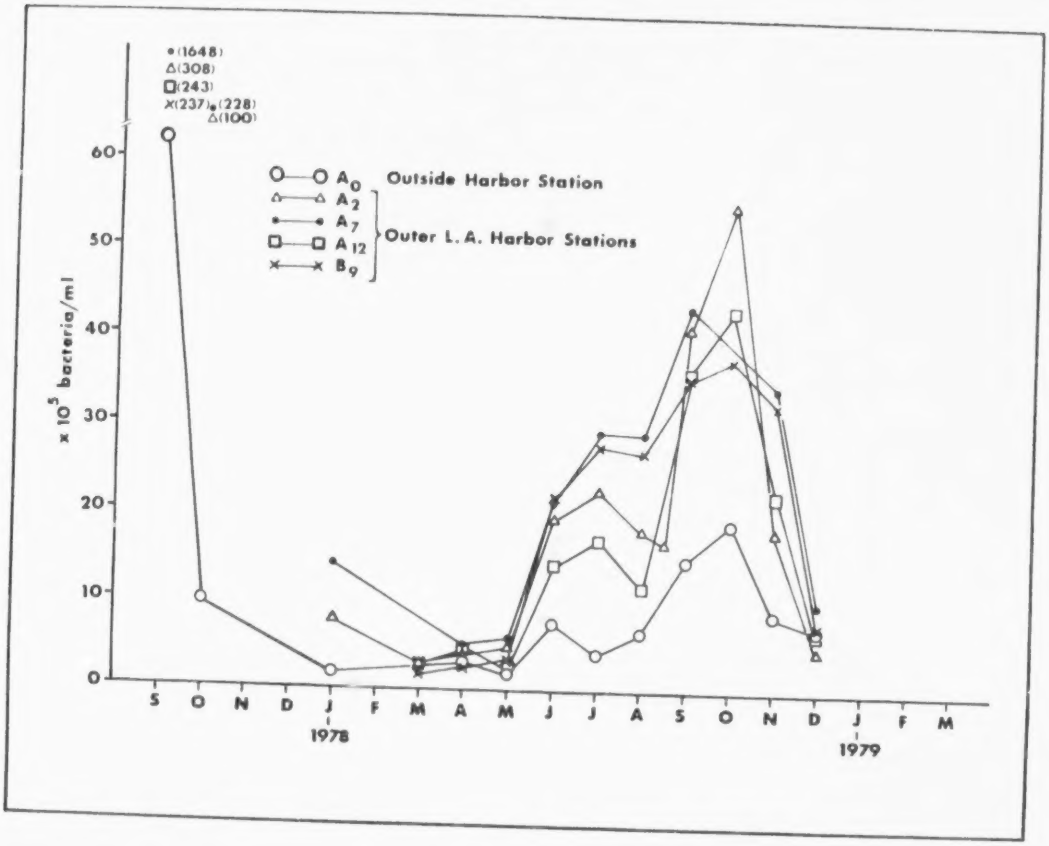


FIGURE 7. TOTAL (>0.2μ) BACTERIAL CONCENTRATION

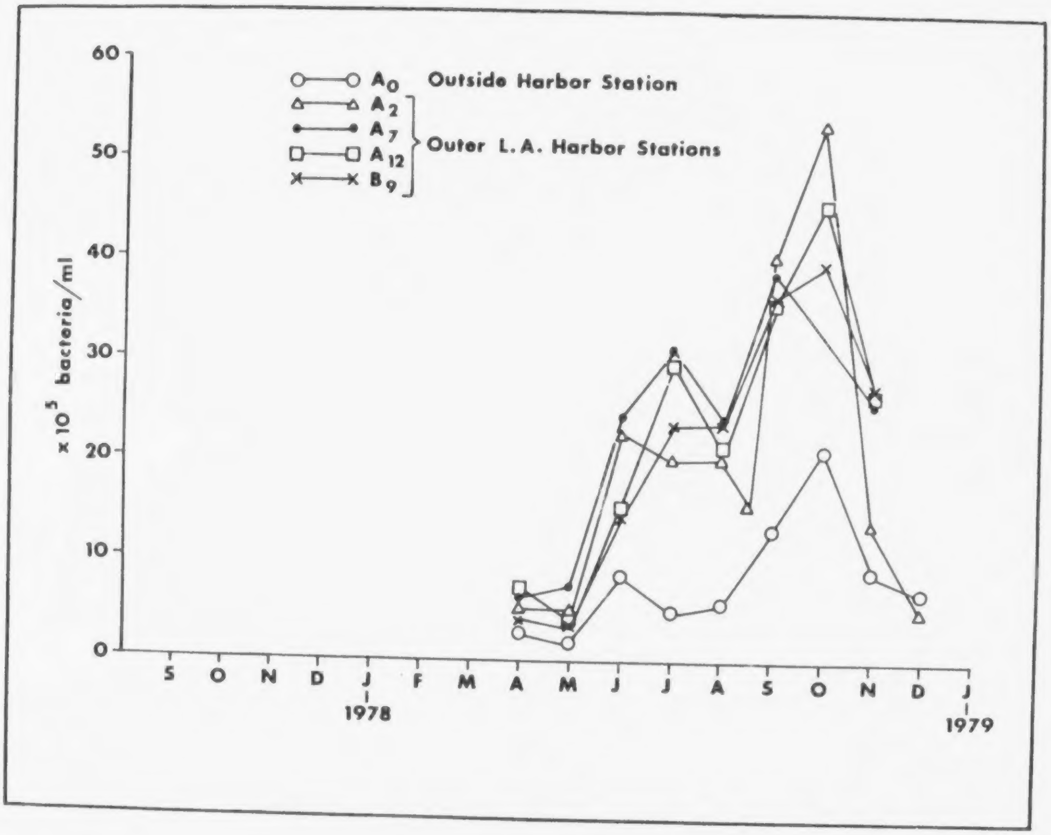


FIGURE 8. ACRIDINE ORANGE DIRECT COUNT (AODC) (<5μ) BACTERIAL CONCENTRATION

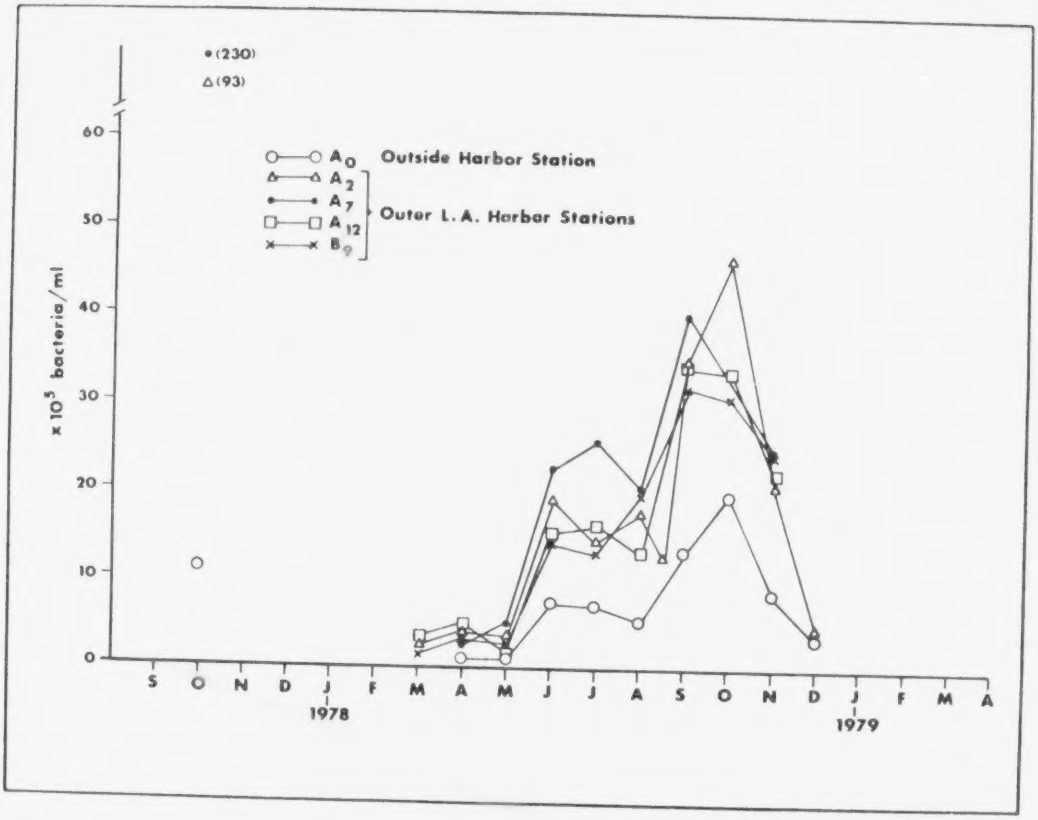


FIGURE 9. ACRIDINE ORANGE DIRECT COUNT (AODC) (<1μ) BACTERIAL CONCENTRATION

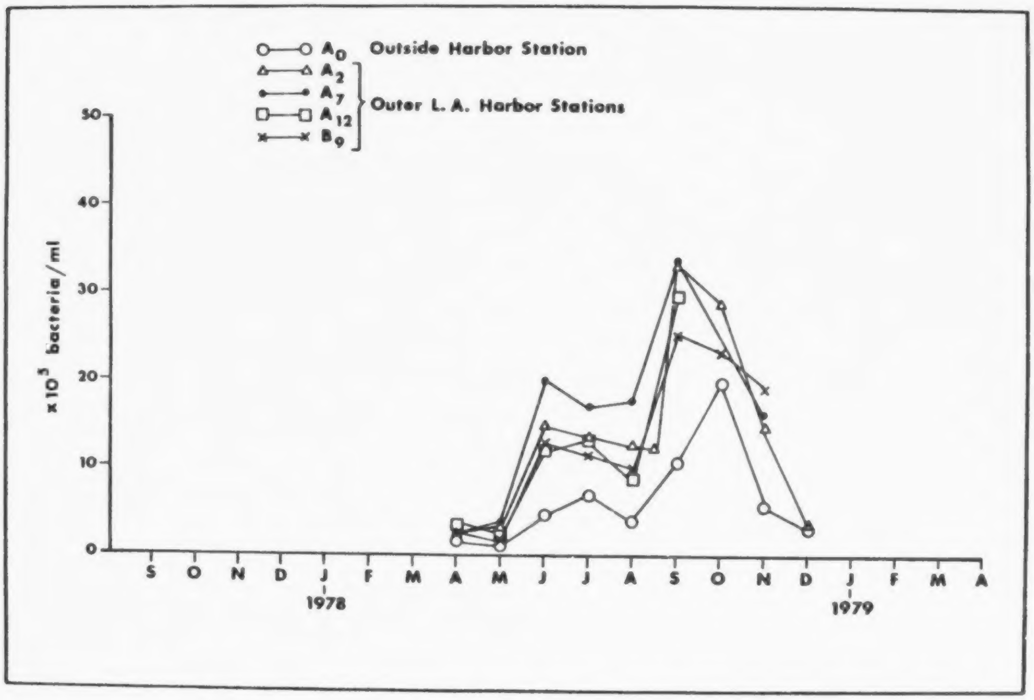


Figure 10. Acridine Orange Direct Count (AODC) (<0.6µ) Bacterial Concentration

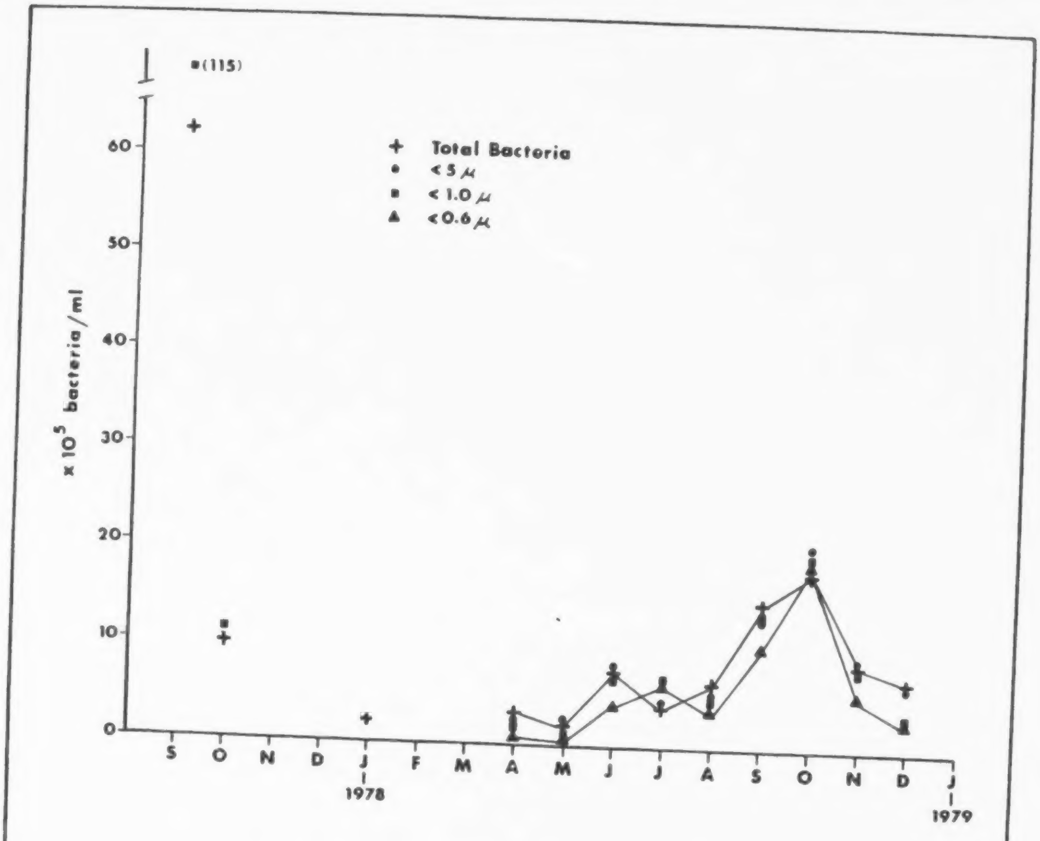


FIGURE 11. STATION AO ACRIDINE ORANGE DIRECT COUNT (AODC)

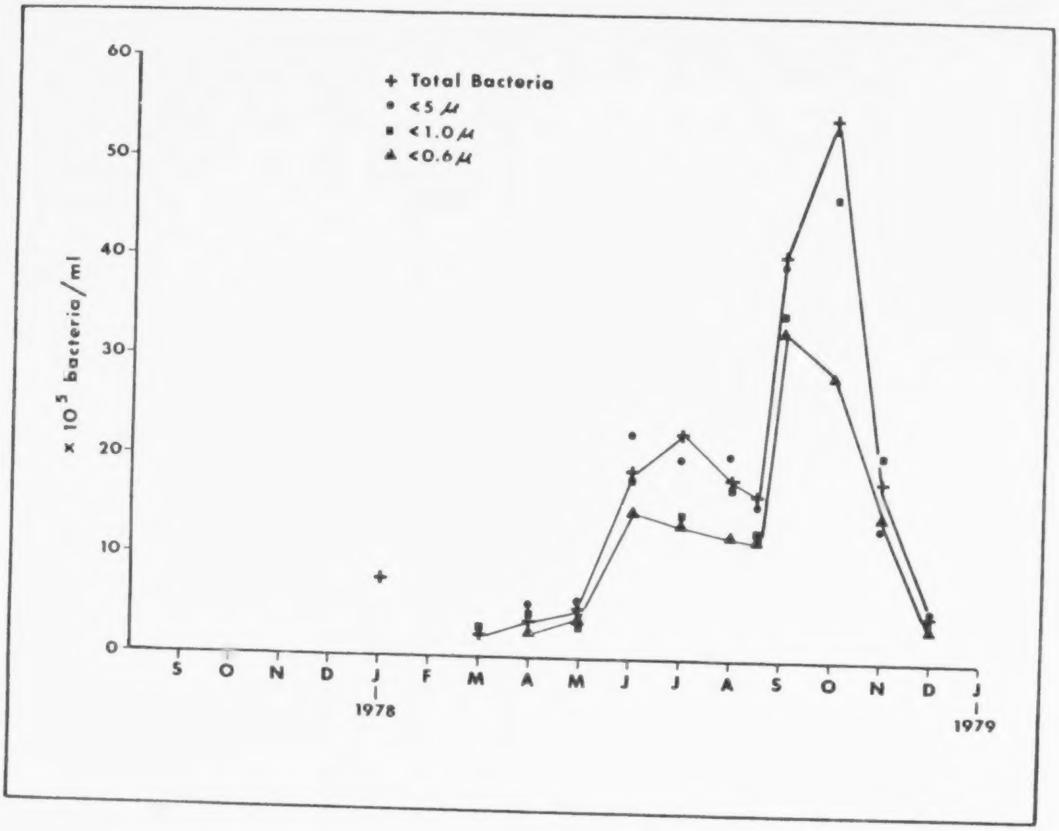


FIGURE 12. STATION A2 ACRIDINE ORANGE DIRECT COUNT (AODC)

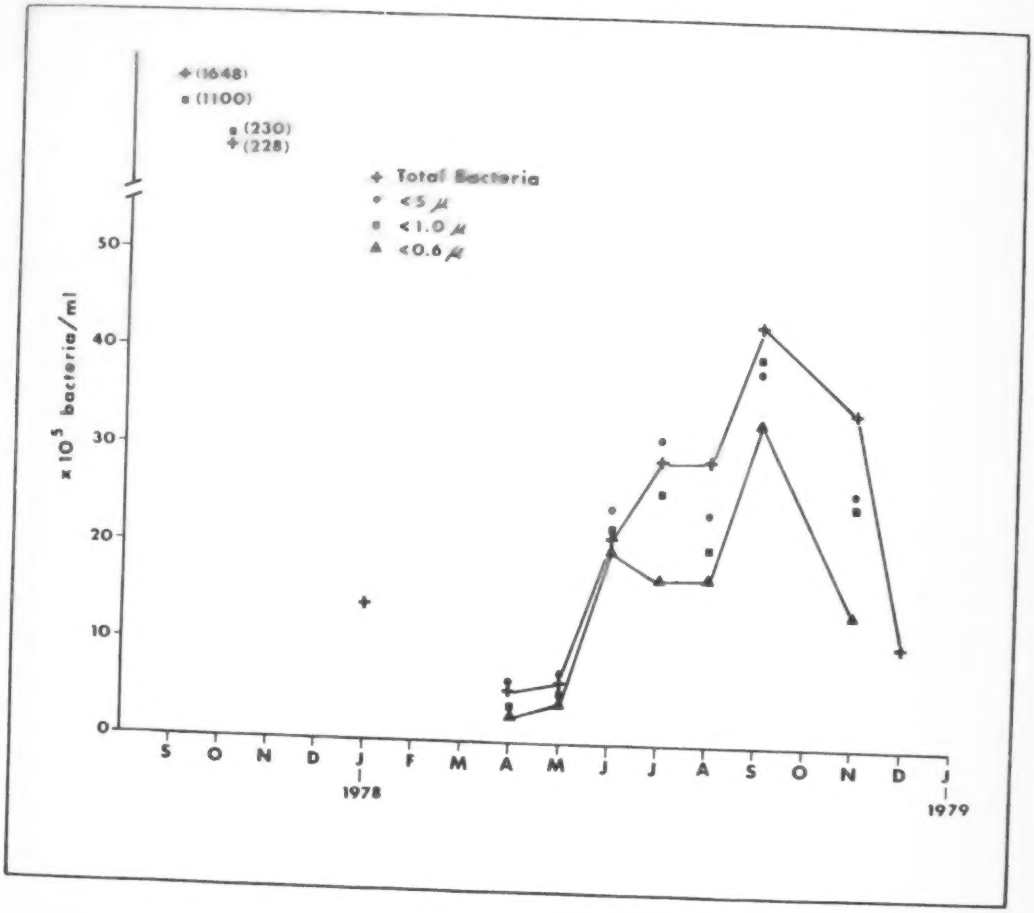


FIGURE 13. STATION A7 ACRIDINE ORANGE DIRECT COUNT (AODC)

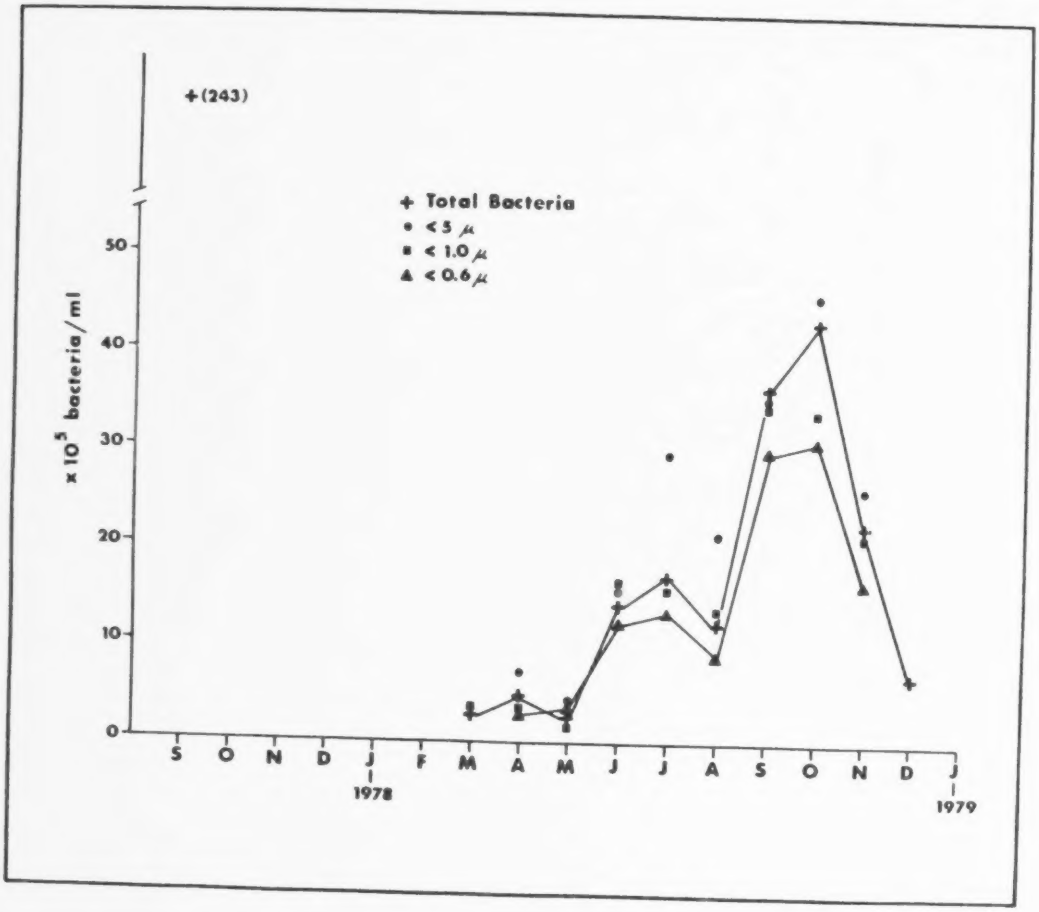


FIGURE 14. STATION A12 ACRIDINE ORANGE DIRECT COUNT (AODC)

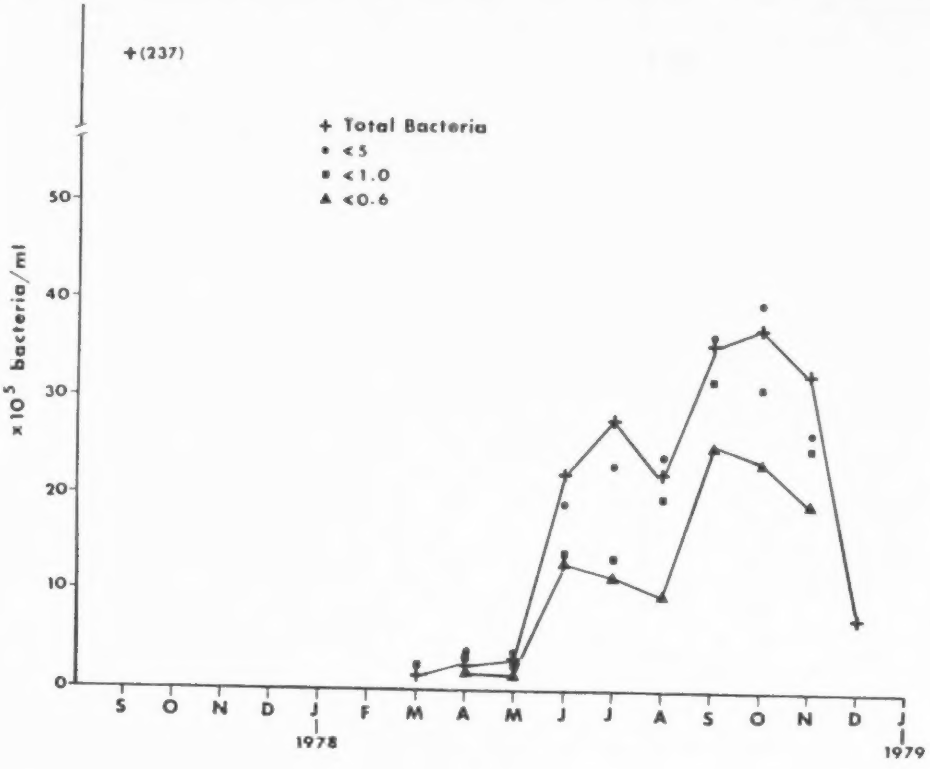


FIGURE 15. STATION B9 ACRIDINE ORANGE DIRECT COUNT (AODC)

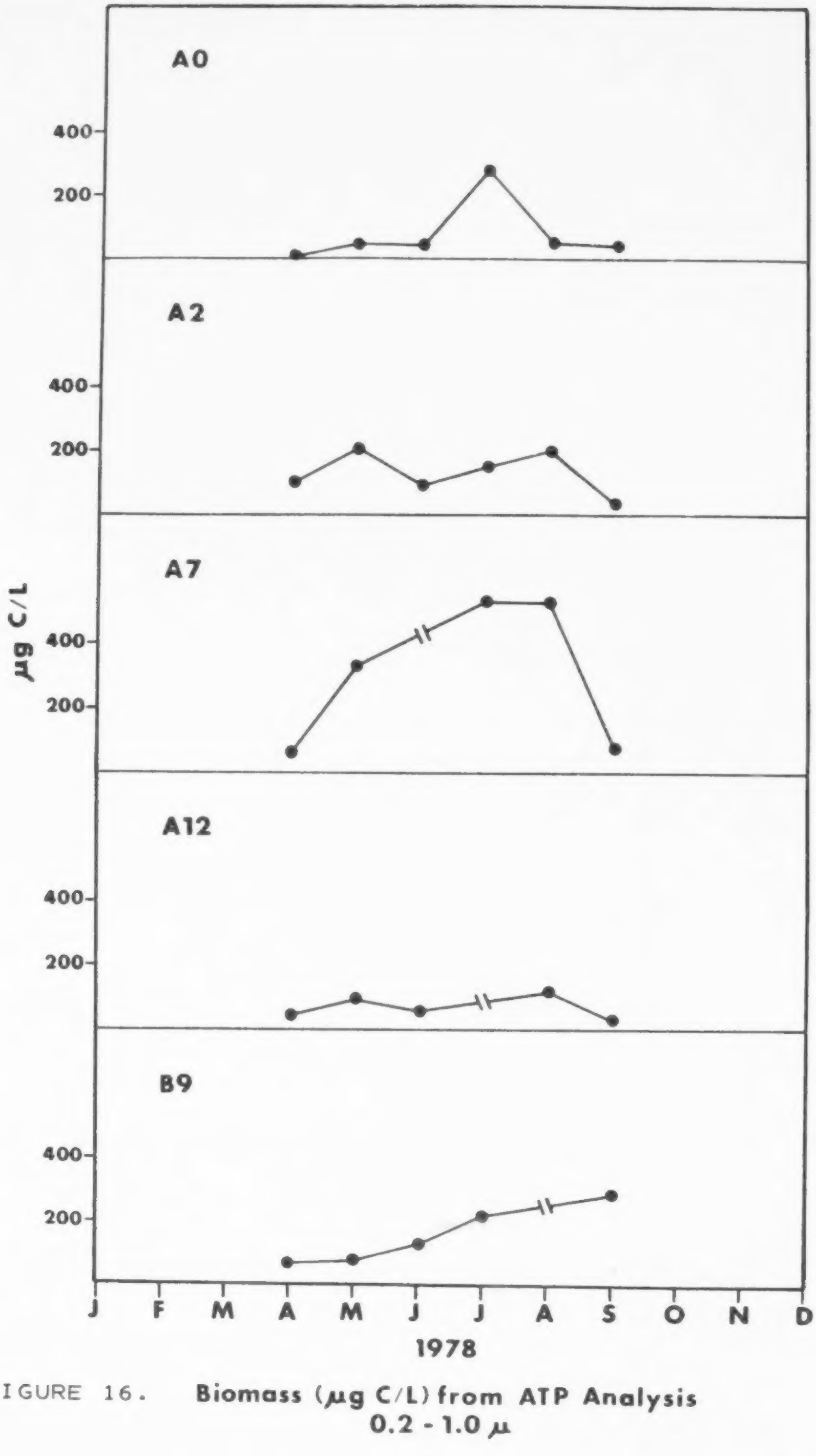


FIGURE 16. **Biomass (µg C/L) from ATP Analysis 0.2 - 1.0 µ**

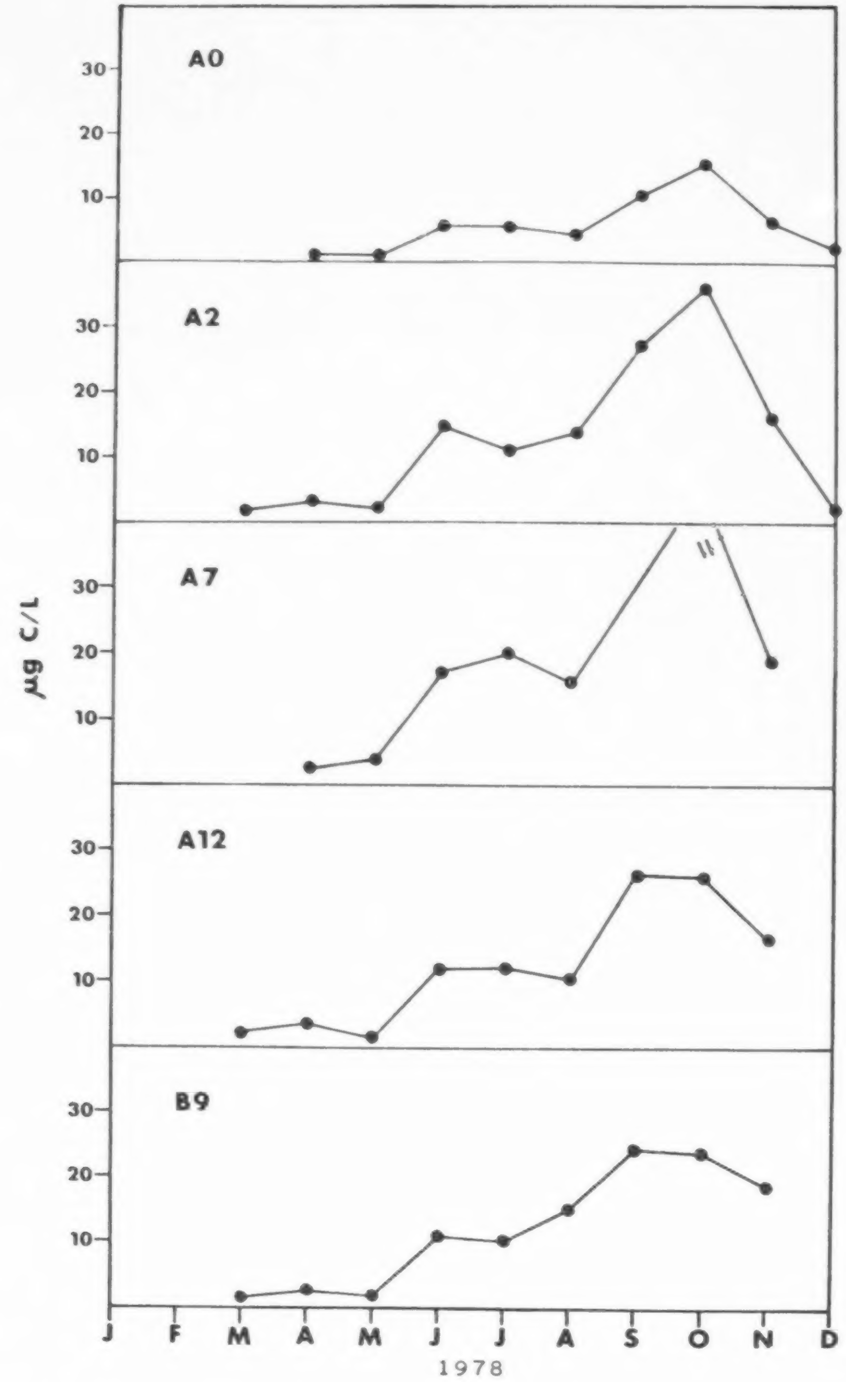


FIGURE 17. **Biomass (μg/L) from AODC <1μ Fraction**

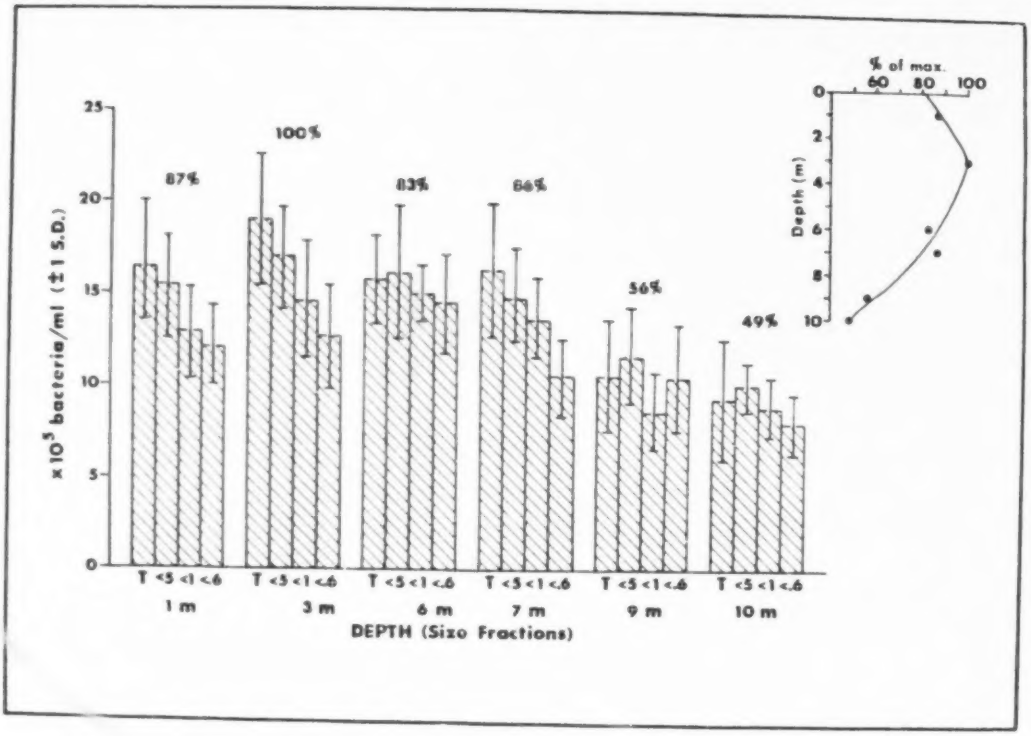
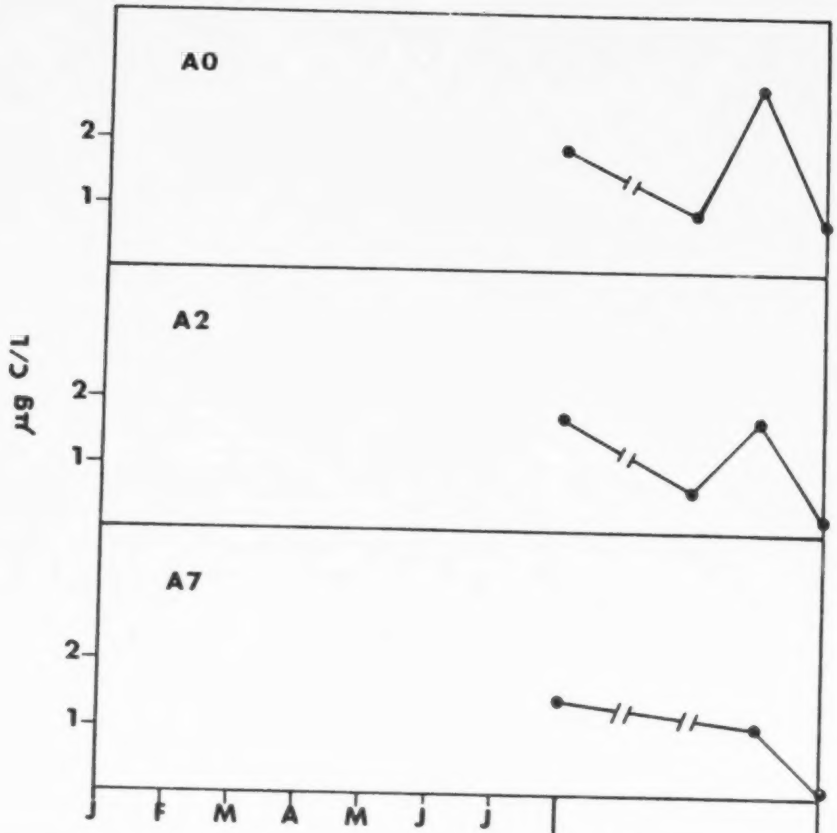


FIGURE 18. 8/17/78 ACRIDINE ORANGE DIRECT COUNT (AODC):A2 BACTERIAL SIZE FRACTIONS VS. DEPTH



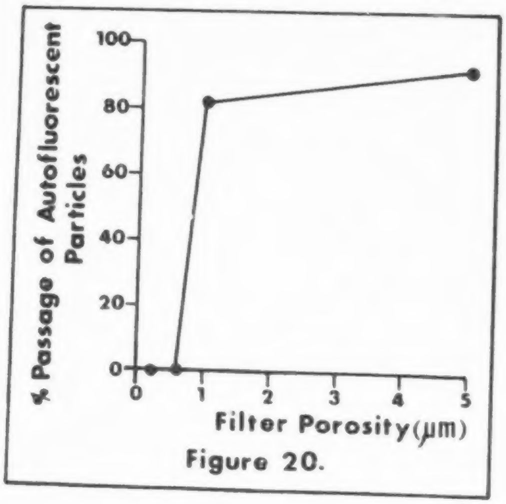


Figure 20.

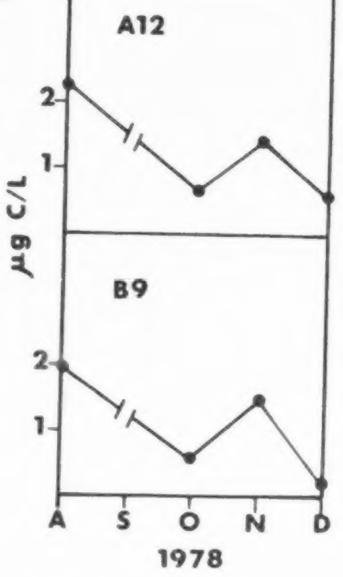


Figure 19. Biomass (μg C/L) from Autofluorescence

THE INGESTION AND UTILIZATION OF LABELED MARINE BACTERIA BY HIGHER TROPHIC ORGANISMS FROM LOS ANGELES HARBOR AND CALIFORNIA COASTAL WATERS

INTRODUCTION

A considerable research effort has been devoted to determine the role of microautotrophs (diatoms, dinoflagellates, monads, etc.) as a nutritional resource for higher trophic levels (zooplankton, suspension and deposit feeders) in aquatic ecosystems. It is now well known that these organisms play a significant role and are considered to be the primary food base for many ecosystems. However, Fenchel and Jørgensen (1977) recently estimated that 40% to almost 100% of the carbon fixed in primary production is utilized by the secondary producers or microheterotrophs (bacteria, yeasts, fungi and Protozoa), depending on the ecosystem in question. Indeed, it does seem reasonable that organisms which rapidly cycle dissolved carbon and produce particulate biomass, such as bacteria, will not go unexploited as a food resource for higher trophic organisms. The role of the detrital food web may be more significant in ecosystems which are either organically enriched or deficient in a necessary component for photosynthesis, i.e., light, nitrogen or phosphate. Pomeroy (1974) has recently pointed out that in the open ocean microheterotrophs play a highly significant role, both in the nutrition of higher trophic organisms and in their long known role in nutrient regeneration.

It is now becoming well established that bacteria serve as a nutritional resource for many aquatic organisms, including planktonic and benthic feeders. The early workers Doflein and Reichenow (1928) stated that some Protozoa, and ciliates in particular, feed upon bacteria; it seemed likely to them that free and attached bacteria were consumed and metabolized in planktonic ecosystems. More recently several investigators (Zobell and Felthan, 1937; Fenchel, 1969, 1972, 1975; Barsdate et al., 1974; and Jørgensen, 1966) have obtained good evidence that bacteria do play a substantial role in the nutrition of deposit and filter feeders. Wavre and Brinkhurst (1971) have demonstrated experimentally that bacteria are digested from the bolus as it passes through the gut of tubificid oligochaetes. Duncan et al. (1974), by means of a simple radioassay, showed that bacteria are ingested and assimilated by the aquatic nematode *Plectus palustris*. Sorokin (1973, 1978) has reported that filter feeders in coral communities, such as sponges, ascidians, sabellid polychaetes, and oysters, are capable of filtering bacterioplankton from the water. He also found that some species of coral, gastropods, and holothurians were capable of ingesting and assimilating bacterial biomass.

The following report is the result of investigations conducted to develop a standard technique which can be used to obtain detailed quantitative information on the flux of bacterial carbon through bactivorous organisms. The method was developed and tested using a marine bacterium as food source and a bactivorous ciliate, *Euplotes* sp., as a predator which utilizes bacteria as a source of carbon and energy. Both organisms were isolated from the Los Angeles Harbor. This technique was then used to determine whether bacteria are ingested and metabolized by: *Euplotes* sp. (Protozoa), *Neanthes arenaceodentata* (Polychaeta), *Macoma nasuta* (Bivalvia), *Mytilus edulis* (Bivalvia), and natural assemblages of microzooplankton (5-203 μm) from five Los Angeles Harbor stations.

MATERIALS AND METHODS

Culture Preparation

The clone of rod-shaped bacteria used for labeling was grown and isolated on Lib-X agar medium. The ^{14}C-labeled bacteria were prepared by growth in an organic-free seawater medium composed of Rila Utility Marine Mix and 50 mg of sodium nitrate in one liter of distilled water, pH 7.8, to which was added fifty microcuries of uniformly labeled ^{14}C-glucose (NEC 042A-1mCi, 37.1 mg in 10 ml) per 100 ml of sterile medium. The culture medium was inoculated by transferring cells from agar medium (Lib-X) using a bacteriological needle. The culture was grown on a shaker table at 18°C for a minimum of five days; two days were required to reach stationary phase, after which the cells were maintained for at least three days in starvation phase to reduce their metabolism of endogenous ^{14}C storage pools. Before the experiments the labeled cells were collected on a 0.2 μm pore size membrane filter (Nuclepore) by gentle vacuum pressure (<7 mmHg), rinsed, and resuspended in chilled seawater medium by vortexing.

Unlabeled bacteria were prepared by growing the same bacterial isolate in a Lib-X medium containing per liter: Rila sea salts (40 g), glucose (1.0 g), trypticase soy broth (2.3 g), and yeast extract (1.2 g), pH = 7.8. The culture was grown at 18°C for 24 h, centrifuged at 10,000 rpm for 10 min, rinsed and centrifuged twice. The pellet was resuspended in unsupplemented artificial seawater and incubated as before for at least 20 h. The cells were centrifuged and washed again before use. The labeled and unlabeled cells were added to the experimental medium to a density which reflects the range of natural standing stocks of bacterioplankton in Los Angeles Harbor. The labeled cells usually comprised less than 10% of the total bacterial population.

Euplotes sp. laboratory studies

Euplotes sp. was isolated from a Los Angeles Harbor water sample by means of an enrichment culture technique. The ciliate stock cultures were maintained in a seawater medium with the addition of brown rice and the natural microflora at 18°C in constant light.

Before the initiation of experiments the culture and medium were passed through a 100 µm mesh to remove large detrital particles. The ciliates were then concentrated four times by a gentle reverse filtration process. This process removes water from inside a column after it passes through a 10 µm mesh which covers the end of the column and is positioned at the bottom of the culture vessel. The water passes through the filter into the column to reach equilibrium with the outside of the column and is removed by a peristaltic pump.

To demonstrate the relationship of grazer concentration to the rate of removal of bacteria from the medium, four dilutions of the ciliate suspension were prepared (20.5, 51, 102, 205 ciliates$\cdot$ml^{-1}) using the ciliate medium previously removed. Since the natural microplankton was already present, only the labeled bacteria were added. Ingestion, respiration and excretion assays (methodology described below) were conducted at 0, 40, and 90 min after initiation of the experiment.

In an experiment to illustrate the relationship between bacterial concentration and grazing rates, the ciliate concentration was held constant and the bacterial concentration was varied (1.28, 1.86, 4.02, 7.85 X 10^6 bacteria$\cdot$ml^{-1}). Unlabeled bacteria inoculated with the 1.0 µm filtrate from a *Euplotes* sp. culture were prepared in the rice-seawater medium and stirred vigorously for 96 h at 18°C. These bacteria were passed through a 25 µm mesh and 0.5, 10^{-1}, 0.5 X 10^{-1}, 10^{-2}, and 0.5 X 10^{-2} dilutions were made with 0.2µm filtered medium. The labeled bacteria were added to each of the dilutions in a constant amount and the experiment was initiated when inoculated with a constant volume of ciliate suspension. The culture was sampled at 0, 40, and 90 min. Ciliate concentration was determined microscopically from four 1 ml replicates, samples were fixed with Lugol's iodide and were counted under a dissecting microscope. Since the labeled bacteria were added in the same amounts, the bacterial concentrate of each dilution had to be determined directly by means of a Petroff-Hauser cell counter and phase contrast microscope.

Benthic invertebrates studies

Experimental specimens of uniform size were selected and starved in beakers of filtered seawater for a minimum of 48 h before the experiment. The medium for *Neanthes arenaceodentata* was decanted twice daily to remove fecal pellets. The valves of the *Mytilus edulis* specimens were brushed, scraped and dried before the experiment to remove any epizoa that might interfere with the results. The individual experiments with invertebrates were modified from the basic plan to accomodate the particular biological requirements of the test organisms. These conditions are described below.

20 October 78 - *Neanthes arenaceodentata*

The fine sand sediment used for this experiment was oxidized with 30% hydrogen peroxide and rinsed thoroughly to remove most organic material. This procedure was carried out with the idea of reducing bacterial growth and metabolism but was later found to have no appreciable effect, so it was discontinued in subsequent experiments. Rila Utility Marine Mix with a suspension of labeled and unlabeled bacteria was used as the assay medium. Each specimen was placed in a 100 ml serum bottle after 5 ml of sediment and 20 ml of medium were added; incubation was in darkness at 17°C. Replicate samples lacking test specimens were prepared for bacterial background controls. Excretion, respiration and ingestion assays were made at 0, 24 and 26 h.

20 October 78 - *Macoma nasuta*

The methods and materials were the same as described above, except the specimens were placed in 125 ml erlenmeyer flasks and 40 ml of medium and 10 ml of sand were used.

27 October 78 - *Neanthes arenaceodentata* - Pulse chase experiment

The pulse chase experiment was designed to observe the metabolic fate of ingested, labeled bacteria during long incubation times. The worms were given a pulse of labeled bacteria for 48 h, rinsed and transferred to medium with unlabeled bacteria (chase) and allowed to feed for 48 h. It was postulated that the absence of observable worm respiration may be due to slow gut passage time and high bacterial background respiration, so the experiment was designed to reduce bacterial background respiration and allow sufficient gut passage time to observe the eventual respiration of ingested bacterial carbon.

In this experiment no sediment was used. Unlabeled bacteria were added to 800 ml of artificial seawater and the labeled cells were added to 500 ml of this medium. Duplicate sets of serum bottles were prepared, one set for initial pulse uptake, and the other set for the subsequent experiment containing 20 ml of labeled medium and one specimen. Ingestion, excretion, and respiration assays were taken at 0 and 48 h. Worms were removed from the duplicate set of bottles and rinsed in filtered sea water and then placed in new bottles with 20 ml of unlabeled bacterial medium. All parameters were then assayed after another 48 h of incubation in darkness at 17°C.

28 November 78 and 8 December 78 - *Mytilus edulis*

After 72 h of starvation the specimens were placed in 125 ml erlenmeyer flasks with the labeled bacterial medium which was prepared from filtered sea water. The first experiment employed 80 ml of medium and all parameters were assayed at 0, 15 and 41 h after incubation at 15°C darkness. The second experiment employed 60 ml of medium and all parameters were assayed at 0, 2, 5, and 24 h. Valve length of *Mytilus* was determined by measuring the left valve after dissection.

Studies on natural bactivorous plankton populations - 2 August 78

An experiment was designed to observe the possible relationship between bactivorous rates of natural microzooplankton (5-203 µm) and natural bacterioplankton standing stocks. Samples were collected on 2 August 1978 from stations A0, A2, A7, A12 and B9 (Figure 6). The samples were passed through 203 µm mesh and then 25% of the liquid sample volume was removed by reverse filtration (discussed above) and passed through a 0.2 µm membrane filter (Nuclepore). The labeled bacteria were added to this filtrate and the preparation was returned to the original sample. It was thus possible to avoid the problem of substantially changing the *in situ* bacterial concentration while adding the labeled cells. The kinetics of ingestion, respiration and excretion were determined by assaying at 0 and 90 min for stations A0, A7, A12, and B9 and at 0, 15, 30, 45, 60, 120, 180, 240, and 360 min at station A2.

Each station had a characteristic bacterial standing stock which was determined monthly by means of epifluorescent counting by D. Krempin; those values are used in this study.

Measured parameter definitions and procedures are detailed in the following paragraphs.

Respiration. Respiration of bacterial carbon was determined by the amount of $^{14}CO_2$ collected after correction for bacterial background and T_0 blank. It is assayed by the methods described by Hobbie and Crawford (1969). Small organisms are placed in 100 ml serum bottles sealed with rubber stoppers and the larger organisms in 125 ml erlenmeyer flasks sealed with rubber stoppers and parafilm. Each data point represents the rate of a single specimen or sample. This sample cannot be used to determine any other parameter, because of the acidification step required by the method. The calculations of respiration rates employed are as follows:

$R_b = (R_{bx} - R_0)$

$R_g = (R_{gx} - R_0 - R_b)/X$

R_b = $^{14}CO_2$ respired by bacterial controls - DPM

R_{bx} = bacterial control $^{14}CO_2$ collected at time point X - DPM

R_0 = $^{14}CO_2$ collected at time point 0 - DPM

R_g = bactivore's respiration rate of $^{14}CO_2$ - DPM/hour

R_{gx} = total $^{14}CO_2$ collected at time point X - DPM

X = time point - hours

Excretion

Excretion is considered to be the flux of dissolved organic carbon-14 into the medium due to biological activity. Bactivore excretion is determined by subtraction of bacterial excretion of ^{14}C. It is determined by removing 5 ml of medium from designated vessels, passing it through a 0.2 µm Nuclepore filter and collecting the filtrate. The filtrate is then acidified to pH 2.0 by addition of HCl and agitated for 20 min to evolve the dissolved $^{14}CO_2$. A 1 ml aliquot of the filtrate is placed in 10 ml of Aquasol scintillation fluor and the radioactivity is measured. The equations employed are the following:

$E_b = E_{bx} - E_o$

$E_g = V(E_{gx} - E_o - E_b)/X$

E_b = DOC^{14} excreted by bacterial controls - DPM/ml

E_{bx} = bacterial control DOC^{14} collected at time point X - DPM/ml

E_0 = DOC^{14} collected at time point 0 - DPM/ml

E_g = bactivore's excretion rate of DOC^{14} - DPM/hour

E_{gx} = total DOC^{14} collected at time point X - DPM/ml

V = experimental medium volume - ml

X = time point - hours

Specific Activity

Specific activity is defined in this study as the total number of bacteria represented by one disintegration per minute (DPM) of carbon-14.

Bacterial numbers in the medium are determined by fixing an aliquot with Lugol's iodide and counting cell numbers in a Petroff-Hauser cell counter on a Zeiss phase contrast microscope. The 14C associated with the labeled bacteria is determined by collecting a 5 ml aliquot on a 0.2 µm filter at 0 h, rinsing twice with chilled sea water, drying and counting on a Beckman LS-100 Scintillation Counter. Specific activity is calculated as follows:

$$SPAC = C/A/v_a$$

A = activity of 0.2 µm filter retentate - DPM

C = bacterial concentration - cells/ml

SPAC = specific activity - bacteria/DPM

v_a = volume of medium filtered for A - ml

Ingestion Rate

Ingestion rate is the total number of bacteria or amount of 14C taken in by the bactivore divided by the time period of incubation after being corrected for metabolic fluxes and T_0 blank. It represents the rate at which the bactivore removes bacteria from the medium.

The activity of the microzooplankton (including *Euplotes* sp. studies) was determined by radioassay of the 5.0 µm filter retentate. At each time point 10 ml aliquots of the assay medium were passed through 5.0 µm Nuclepore filters and rinsed twice with 10 ml of chilled sea water, dried, and counted in Toluene, PPO, POPOP scintillation fluor. The 0 h filters represent the bacterial background activity which is corrected for metabolic fluxes and subtracted from the other time points.

The radioactivity associated with metazoans was determined as follows: The specimens were removed from the medium and placed in filtered seawater for a 10 min rinse to remove extraneous labeled bacteria from metazoan surfaces. Soft-bodied specimens were placed in scintillation vials with 1 ml of Protosol (New England Nuclear) and homogenized.

The bivalves were opened and all tissue was removed with a scalpel and placed in a scintillation vial with 1 ml of

Protosol and homogenized. Samples were allowed to digest overnight and then were heated to 55°C for 30 min for final digestion. To reduce color quenching 0.1 ml of 30% hydrogen peroxide was added and the samples were heated for 30 min at 55°C. The following day Aquasol scintillation fluor was added and the samples were counted. Bacterial ingestion rate is calculated as follows:

$$L = (E_b + R_b/V_r)/A/V_a$$

$$I_d = F_x - F_0 (1 - L) + E_g + R_g$$

$$I_b = I_d (SPAC)/X$$

F_0 = activity of bactivore at time point 0 - DPM

F_x = activity of bactivore at time point X - DPM

I_b = ingestion rate - bacteria/h

I_d = total activity ingested, including metabolic corrections - DPM

L = proportion of bacterial metabolic losses from blank at time point X - 0.XXX

V_r = volume of respiration assay - ml

RESULTS

Euplotes sp. laboratory studies

In the experiment to demonstrate the relationship between grazer density and rates of bactivory, the bacterial concentration was 1.3 X 10^6 cells·ml^{-1} and 48% of these cells were carbon-14 labeled. The ingestion and metabolic rates were almost linear for the 90 min incubation period with a slight break after 40 min. The data presented in Figure 1 and Table 1 are based on the 40 min data points, because they are thought to be more representative of the actual rates.

Figure 1 illustrates the linear relationship between grazer population density and grazing rate. It can be seen that the number of bacteria removed from the medium is directly proportional to the number of grazers (*Euplotes* sp.) present in the medium. The linear regression correlation to the data points is 0.996 and is viewed as being significant. This observation gives an indication of the reliability of the methodology in determining bacterial grazing rates. In this experiment bacterial concentration was probably not limiting during the incubation period.

Table 1 illustrates that, in samples with a higher grazer density, fewer bacteria per individual grazer are consumed. This is probably due to fewer available bacteria in samples which have stronger competition for resources and indicates the importance of the relative grazer/bacteria concentration. The data also reveal an inverse relationship between grazer density and bacterial population turnover time. In other words, the more grazers present the more rapidly bacteria will be removed from the medium. Respiration and excretion data do not reveal any significant trends related to grazer density. Overall, approximately 12-16% of the ingested bacterial biomass is used in predator energy metabolism, as indicated by the respiration of bacterial carbon.

In a related experiment the grazer population density was held constant and bacterial concentration was varied. Figure 2 illustrates the relationship between specific ingestion rates and bacterial population density. The relationship seems to be a hyperbolic function and analagous to that described by Michaelis-Menten saturation enzyme kinetics. The last pair of points seems to approach the saturating concentration, although two sets of higher points are necessary to confirm this idea.

In the bacterial concentration range examined, the population turnover time data displayed no significant trend related to bacterial concentration according to data presented in Table 1. As presented in Figure 2, excretion and respiration rates displayed a similar pattern of saturation kinetics, while ingestion rates and excretion rates seem to be reduced at or near saturation for ingestion. It is interesting to note that in the most concentrated sample a ciliate is six times more likely to encounter a bacterium than in the least concentrated sample and the specific ingestion rate demonstrated experimentally was 5.5 times greater.

Benthic invertebrates studies

20 October 78

In experiments to demonstrate the uptake and utilization of bacterial biomass, *Neanthes arenaceodentata* displayed no adverse reactions to the chemically oxidized sand such as had been observed earlier in thermally combusted sediments. The worms formed burrow tubes and assembled mucus nets above the sediment.

Bacterial numbers were determined to be 4.6 X 10^6 cells/ml which may be slightly low for the natural sediment-water interface. The respiration assay failed to yield respiration above bacterial background (see Table 2.). The excretion data reveal that 87.8 to 99.6% of the ingested labeled bacterial biomass was excreted. During the experiment these worms ingested 1.9 X 10^7 bacteria/day or approximately 20.6% of the available bacteria. (text continued on p.12)

TEXT TABLE 1

SUMMARY OF BACTERIAL INGESTION AND UTILIZATION BY *Euplotes* sp.

Sample	Incubation Time (min)	Ib/Ind Ingestion Rate (Bact/Indv/Min) Mean	Range	Tt Turnover Time C/Ib (h)	Respiration Rate of Bacterial Biomass % Ingested/Hour Mean	Excretion Rate of Bacterial Biomass % Ingested/Hour Mean
Grazer Density						
20.5 ciliates·ml^{-1}	40	43.3	41.9-44.7	24.4		
51	40	36.6	23.4-49.8	11.6	4.1	11.6
102	40	35.8	32.9-38.7	5.9	3.3	11.6
205	40	32.0	31.7-32.3	3.3	3.6	9.1
Bacterial Density						
1.28x10^6 cells·ml^{-1}	70	20.0		130.0	3.9	17.7
1.86	40	33.5	28-39	114.0	7.3	42.0
4.02	40	84.0	75-93	75.2	5.2	46.5
7.85	40	110.0	105-115	112.2	14.8	40.9

TEXT TABLE 2

SUMMARY OF BACTERIAL INGESTION AND UTILIZATION BY METAZOANS

Species	Date	No. of Specimens	Size Range	Ingestion Rate (Bact/Indv/Day)		Ingestion-Efficiency (100 x Ingested/ Available) %	Respiration Rate of Bacterial Biomass % Ingested/Day		Excretion Rate of Bacterial Biomass % Ingested/Day	
				Mean	Range		Mean	Range	Mean	Range
Neanthes arenaceodentata	10-20-78	12	100-120mg	1.9×10^7	$1.7-2.1 \times 10^7$	20.6	N.D.*	N.D.	93.7	87.8-99.6
(1)*Neanthes arenaceodentata*	10-27-78	12	100-120mg	2.2×10^9	$1.5-2.8 \times 10^9$	97	N.D.	N.D.	22.4	16.3-28.6
Macoma nasuta	10-20-78	12	15-20mm	5.4×10^6	$4.3-7.8 \times 10^6$	5.9	N.D.	N.D.	58.0	39.6-77.8
Mytilus edulis	11-28-78	10	18-23mm	2.0×10^8	$1.1-3.2 \times 10^8$	52.1	8.0	7.0-9.0	1.0	0.8-1.2
Mytilus edulis	12-8-78	16	17-24mm	1.4×10^8	$0.5-2.5 \times 10^8$	16.5	5.0	2.8-8.6	N.D.**	N.D.

*N.D. = Not Demonstrated. Data failed to yield significant results above bacterial background.

(1) Data for this experiment was not corrected for excretory or respiratory fluxes.

**N.D. = Not Demonstrated. Samples lost due to defective scintillation fluor.

In a similar experiment which used *Macoma nasuta* as the test organism, the mud clams did not burrow into the sediment, but remained lying on the surface; experimental conditions apparently were not optimal. The specimens did, however, appear to be pumping with their siphons. Respiration of bacterial biomass was not demonstrated above background (Table 2) and the specimens were found to excrete 39.6 to 77.8% of the ingested bacterial biomass. Also note that they ingested only 5.4 X 10^6 bacteria/day or approximately 6% of the available bacteria.

27 October 78

In the pulse chase experiment which utilized higher bacterial numbers and an absence of sediment, *Neanthes arenaceodentata* was observed to form mucus tubes and mucus nets above them. Bacterial concentration was determined to be 7.75 X 10^7 cells/ml. These specimens appeared to be very efficient at removing bacteria from the water under the experimental conditions. They ingested 1.5 to 2.8 X 10^9 bacteria/day (Table 2) which represents ingestion of approximately 97% of the available bacteria. These data were not excretion-corrected because of technical problems. Respiration of $^{14}CO_2$ above bacterial background was not demonstrated for *Neanthes arenaceodentata*.

Table 3 illustrates that the activity of the animal homogenate is substantially reduced after 48 h and excretion accounts for approximately 13% of this reduction. Fifty-one percent of the loss from the animal homogenate was not accounted for and no significant respiration of $^{14}CO_2$ was exhibited.

Text Table 3

27 Oct 78 *Neanthes arenaceodentata* Bacterial Uptake Pulse-Chase Experiment

Time	Activity of Animal Homogenate DPM	Activity of Flux into DOC^{14} DPM	Activity Unaccounted DPM	Unaccounted % Loss
0	126154			
48 h	45048	16800	64306	51

28 November 78

The data for an experiment designed to test whether the mussel, *Mytilus edulis*, ingests and utilizes bacterial biomass is presented in Figure 3 and Table 2.

The bacterial concentration was 4.8 x 10^6 cells/ml at the outset of the experiment. This is within the range of the standing stocks of bacterioplankton observed in the Los Angeles Harbor. The data demonstrate that small *Mytilus edulis* individuals effectively filter free bacterioplankton from the water at a rate of 1.1 - 3.2 X 10^8 cells/day (Table 2) which represents an ingestion efficiency of approximately 52%. The data also clearly illustrate that the ingested bacterial biomass is metabolized (Table 2). During the experimental period, approximately 8.0% of the ingested biomass was respired and approximately 1.0% was excreted. Figure 3 shows the kinetics of ingestion over the experimental period. It is readily apparent that uptake is faster in the first 15 h and slows down in approaching hour 40. The ingestion estimates appearing in Table 2 are based on the average of all data and should be considered conservative; the actual ingestion rate may be higher. The method employed yields an underestimate of feeding rates, due to bacterial division and hence a dilution of the label.

8 December 78

The preceding experiment was repeated to test the effects of bacterially-enriched conditions on uptake and utilization rates. The bacterial concentration in this experiment was higher (1.41 X 10^7 cells/ml) than in the previous experiment and represented conditions in an organically enriched environment. Table 2 presents data that show that the test organisms (*Mytilus edulis*) ingested bacteria at a rate comparable to that of the previous experiment (0.5 - 2.5 X 10^8 cells/day) and removed approximately 16% of the available bacteria from the suspension. Again, these figures are based on the average rate from all data points. Ingestion kinetics (Figure 3) appear to be linear for the first 5 h and to decelerate for the next 19 h. Five percent of the ingested bacterial biomass was respired by the test organisms (see Table 2). Excretion data are not available, because the samples were lost due to defective scintillation fluor.

Natural bactivorous plankton studies

These studies are designed to determine the seasonal variation in the rates at which bacterial populations are being turned over by bactivorous plankton grazing in Los Angeles Harbor. The data presented in Figures 4 and 5 express grazing rates in terms of bacteria ingested per unit volume and time, because the species composition of the bactivores is not known.

Figure 4 compares the bactivore's grazing rate with the bacterial standing stock at the five stations sampled. A direct and significant ($r = 0.945$) correlation can be seen between the two parameters. It should be noted that these rates may reflect the grazing rates of individual bactivores and/or the population density of bactivores. Table 4 presents ingestion and utilization data for this study. The turnover times for the bacterioplankton populations by bactivorous grazing ranges from 11.6 to 18.8 h. The rates of all five stations are comparable and are not significantly different. The respiration and excretion data show no trend related to bacterial standing stock in the terms expressed in Table 4. This may be a function of variability in bactivore population size, composition and activity. Bactivores with low grazing efficiency or with strong competition pressures will have to expend more metabolic energy than more efficient bactivores or those that are in less competitive situations.

Text Table 4

Summary of Bacterial Ingestion and Utilization by Natural Bactivorous Plankton Populations

Stn.	Bacterial Density C (bacteria x $10^{9}\cdot L^{-1}$)	Ingestion Rate Ib (bacteria x $10^{6}\cdot L^{-1}\cdot mm^{-1}$) Mean	Range	Turnover Time C/Ib (h)	Respiration Rate of Bacterial Biomass (% ingested / h) Mean	Excretion Rate of of Bacterial Biomass (% ingested / h) Mean
A0	0.64	0.9	0.8-1.0	11.6	18.0	39.0
A2	1.79	1.6	1.4-1.7	18.8	40.0	44.2
A7	2.89	3.2	2.8-3.7	14.9	35.0	33.7
A12	1.17	1.4	1.3-1.6	13.7	10.5	14.5
B9	2.17	2.4	2.3-2.5	15.1	40.8	6.4

Figure 5 represents kinetics of bacterial ingestion by the bactivorous plankton from station A2 during a 6 h incubation period and the data points represent total ingested activity of bacteria corrected for respiratory and excretory fluxes. Although the correlation of the regression line ($r = 0.87$) is not considered highly significant, it appears that ingestion occurs at a fairly linear rate during the incubation period.

DISCUSSION

Euplotes sp., laboratory studies

The experiments performed on laboratory cultures of *Euplotes* sp., may illustrate some very basic and obvious ecological principles; *i.e.*, there is a direct relationship between the rate of removal of a food source from the environment and the density of grazers, or that each grazer gets less of a resource as competition for that resource increases. However, these ideas have been well borne out in other works and were not the objective of this study. What this aspect of the study has provided is a reliable method for quantification of the ingestion and metabolic utilization of bacterial carbon by bactivorous plankton, as is postulated to occur in Los Angeles Harbor or other marine environments.

The study has illustrated that a monoculture of a bactivorous plankter will remove bacteria from its medium at a rate directly proportional to the concentration of bactivores. In effect, the turnover time (T_t) of a bacterial population appears to be inversely related to bactivore population density. This investigation has also demonstrated that as competition for food resources increases, caused by increasing bactivore population density, each individual predator is able to capture less of that resource. The data did not reveal any significant trends in terms of metabolic energy expended related to competitive pressure. This may be due to some inherent variability of the methodology, or to the fact that this phenomenon may require greater resolution or sensitivity than was designed into these experiments.

A relatively small portion (12-16%) of the ingested bacterial carbon was used for maintenance metabolism (respiration and excretion). This may be attributed to the detritus and organically enriched medium employed, which may also have been utilized as a food resource and metabolized by the bactivores. In addition, the carbon-14 incorporated into the bacteria is probably mostly high molecular weight molecules, *i.e.*, protein, and is more likely to be used in anabolic rather than catabolic processes by the predators. This would support Fenchel and Jørgensen's (1977) proposal that bacteria are an efficient and energetically advantageous food source due to their low C:N ratio.

Ingestion kinetics which show resource saturation are also suggested by this study. It follows that bactivores have a maximal rate of grazing (Michaelis-Menten Vmax) and only attain this rate when the food resource is present at some characteristic concentration. At subsaturating bacterial concentrations, the ingestion rate will vary with food availability. The application of the Michaelis-Menten model to the data presented here illustrated this phenomenon; *i.e.*, initially the ingestion rate increased rapidly with small changes in bacterial concentration, and as resource saturation was approached the ingestion rate declined. This suggested attainment of a constant rate with no acceleration. The excretion and respiration data show similar kinetics, and the rate of excretion appears actually to decrease. It seems logical to assume that the metabolic expenditure to capture food is inversely proportional to food availability. The data presented in this study suggest that respiration and excretion follow a similar pattern of saturation kinetics, and that rates may even be reduced at or near the saturation point due to optimization of capture success.

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The results of these experiments have answered a few necessary questions. First, they demonstrate that the method employed can be used to demonstrate bacterial ingestion and utilization by microzooplankton. They establish that bacteria do play a nutritional role for *Euplotes* sp. The magnitude or significance of this role has not been established and will require further study. The techniques have also been useful in demonstrating predator-prey or grazer-plankton relationships in a closed system. This study also demonstrates the potential of this assay for use with other organisms and in other circumstances.

The results of these studies indicated that a correlation between bacterioplankton standing stock and rates of production, and the feeding activity and standing stock of bactivorous organisms could be demonstrated in nature.

Benthic invertebrate studies

The results of the experiments with *Neanthes arenaceodentata* demonstrate that these organisms do ingest bacteria collected from both the sediment and the overlying waters. It appears possible that not only do they ingest the sediment and digest organic bacteria and matter, but they also may reingest the secreted mucus net after bacteria have been collected and colonized on it. In the experiment which contained no sediment, it appeared to be the only efficient means of gathering bacteria in the absence of sediment. It is also possible that *Neanthes* may ingest their fecal pellets after they have been colonized by bacteria, as has been proposed by Frankenberg and Smith (1967). However, this parameter was not considered in this study.

The absence of demonstrable respiration of $^{14}CO_2$ is surprising and hasn't been encountered in previous work. It may be that the respiration rate of the worms is quite low and that the labeled bacteria have enhanced respiration in the presence of the worms, so that the total $^{14}CO_2$ collected is comparable to the bacterial controls. Also, bacterial carbon, being largely protein, may go into biosynthesis rather than energy metabolism of the metazoans. Excretion values are significant and do indicate that the bacteria are being metabolized.

The pulse chase experiment showed that 64% of the ingested ^{14}C was lost after 48 h. Excretion accounted for 13% of this loss and the rest was not accounted for. It may be that this ^{14}C was contained in the fecal pellets. It cannot be determined whether all the activity remaining in the animal homogenate is actually assimilated bacterial biomass without knowing the gut passage time.

The data from *Macoma nasuta* suggest a relatively low uptake rate per animal. The rather low ingestion rate could be a reflection of two possibilities. The clam may not have been feeding very actively, due to suboptimal sediment conditions and/or their filtering apparatus may be inefficient at filtering particles as small as free bacteria. The excretion data did, however, demonstrate some uptake of bacterial biomass.

The experiments with young *Mytilus edulis* yielded the most convincing results, supporting the hypothesis that bacterioplankton play a nutritional role for some filter feeding benthic invertebrates. Individuals 17-24 mm in length were capable of ingesting 0.5 - 3.2 x 10^8 bacteria·day^{-1}. The experiments also yielded comparable metabolic activity results. This species seems to be quite efficient at filtering free bacteria from suspension. The different uptake efficiency figures among different organisms (Table 2) are probably a function of the difference in bacterial numbers in the two experiments. The difference in the ingestion kinetics may be a result of possible oxygen limitation in the second experiment due to higher bacterial numbers.

The method suffers from the disadvantage that all parameters (uptake, ingestion, respiration, etc.) cannot be determined from the same individual. In order to get a broader data base, experiments should be performed using a greater number of uniformly sized specimens as well as using different size classes of metazoans. Greater replication may yield more conclusive results. The data presented herein lead to the conclusion that bacterioplankton can play a nutritional role for local benthic invertebrates *in situ*.

Natural bactivorous plankton studies

This study is the first in what will be a periodic sampling program to correlate standing stocks and activity of bactivorous plankton microheterotrophs in Los Angeles Harbor. This work is designed to complement that which is being conducted on the detrital food web and the carbon cycle in Los Angeles Harbor. The overall goal is to elucidate the dynamics of secondary production in Los Angeles Harbor.

The data presented here illustrate a direct correlation between bacterial grazing rates and bacterial standing stocks. This indicates that standing stock and/or specific grazing rates of natural populations of bactivorous plankton vary directly with bacterial standing stock and production. It is postulated that in an organically enriched marine system bacterial production is enhanced, which in turn enhances bactivorous plankton production, and so on. In this bacterial enhancement scheme, which is the detrital food web, bacterial production is in equilibrium with bactivorous ingestion. It is thought that in situations which are not nutrient- or oxygen-limited, this enhancement scheme will be balanced. In defense of this statement, one can look at the turnover time (Tt) of the bacterial population by bactivorous grazing at each station compared to bacterial standing stock. The turnover time at station A0 was 78% that of A7, while the bacterial standing stock of station A0 was 22% that of A7. However, this may not be the case in organically enriched waters, in which high rates of bacterial production, and hence of high oxygen uptake, will inhibit the activity of other organisms.

No significant trend for metabolic activity or utilization compared to bacterioplankton standing stock could be demonstrated due to the heterogeneity of the bactivorous plankton populations. It can be said that a substantial portion of the ingested bacterial biomass was used in energy metabolism (25-84%). Again, this wide range can be attributed to heterogeneous bactivore populations with varying feeding efficiencies and competitive abilities. One expects fairly high metabolic rates for these bactivores due to high energy requirements for their motility and feeding mechanisms.

The kinetics of ingestion seem to be fairly linear for the first six hours of incubation; thus instantaneous ingestion rates can be calculated for time periods less than 6 h. Based on previous work, an incubation period less than six hours is desirable, because beyond this time the labeled cells will start to be diluted due to cell division of the predominantly unlabeled bacteria, thereby reducing the specific activity of the label. The result is that the grazer will encounter the same number of bacteria and fewer of them will be labeled. Also, considerable recycling of excreted ^{14}C might occur. This will manifest itself in the data as a decrease in the ingestion rate, as demonstrated by the radioassay, but in reality the ingestion rate may be constant through time. On the basis of this information, short-term (less than 6 hours) incubations are preferred for kinetics studies.

In summary, this study suggests that bacterial ingestion by bactivorous plankton may be at steady state with bacterial production. A significant amount of ingested bacterial biomass is used in energy metabolism. The natural plankton population can be assayed for bactivorous activity under natural concentrations and conditions. In order to make more definitive statements about the role of bacteria in the energy budget of bactivores, more information about the identity, biomass, and growth rates of the bactivores is necessary. More attention must be paid to the species composition and carbon content of the dominant bactivorous plankton.

SUMMARY

The results presented in this study demonstrate that bacteria do serve as a food source for higher trophic organisms found in Los Angeles Harbor, including Protozoa and some invertebrates. These findings support the proposed importance of the

detrital food web in marine ecosystems currently found in the literature. It has been suggested that in many ecosystems the microheterotrophs (bacteria, etc.) play a substantial role in the nutritional support of higher trophic organisms.

This study suggests that a shift in dominant species towards species that can utilize bactivory for nutrition will be seen in waters which are organically enriched. There is also evidence which suggests that bactivory is in steady state with bacterial production; *i.e.* bactivore standing stock and feeding activity will be balanced with bacterial production which, in effect, is dependent on organic input. For example, areas of Los Angeles Harbor which receive organic wastes have a comparatively high rate of bacterioplankton production and one would expect high rates of feeding and production among the bactivorous plankters and benthic invertebrates in these waters. From the evidence presented here and in the literature, one would expect the microheterotrophs to play a more substantial role as a food base in these organically enriched systems than in phytoplankton-based systems. In conclusion, ecosystems which are bacterially enriched and yet perhaps poor in phytoplankton production may be as productive overall as other phytoplankton-based ecosystems.

The study also provides evidence that the assay methods developed may be employed to investigate bactivory in microscopic plankton as well as in deposit and filter feeding benthic invertebrates. It is believed that this method, with the appropriate modifications, will be useful in elucidating the pathways and dynamics of carbon in the detrital food web. The major points of this study are presented below.

1. Experiments with laboratory isolates of *Euplotes* sp. and a marine bacterium were instrumental in developing and demonstrating the accuracy of the techniques. A direct relationship between *Euplotes* sp. concentration and rate of removal of bacteria from suspension was observed. These data provide evidence that the results obtained by this method accurately reflect bactivorous activity.

2. A hyperbolic relationship between grazing rates and bacterial concentration was suggested. These findings show that a critical grazer space:bacteria ratio in the experimental design is necessary to yield maximum potential rates of ingestion, respiration, and excretion.

3. Results from studies with the benthic invertebrates, *Neanthes arenaceodentata*, *Macoma nasuta*, and *Mytilus edulis* indicate that these organisms do ingest bacteria by an assortment of means and utilize bacterial biomass to varying degrees.

The ingestion rates reported are probably underestimated, because fecal material was not assayed and because of the reduction in specific activity due to bacterial cell division during long incubation periods (> 6 h). It was found that bacterial ingestion rates varied with experimental conditions.

4. Studies with natural populations of bactivorous plankton (5-203 μm) indicate that the rate of removal of bacteria from suspension by bactivory is directly related to *in situ* bacterial concentrations. The results suggest that the grazer's standing stock, ingestion rates, grazing efficiencies, or a combination of these will be in equilibrium with bacterial production in natural planktonic communities.

LITERATURE CITED See Section VI

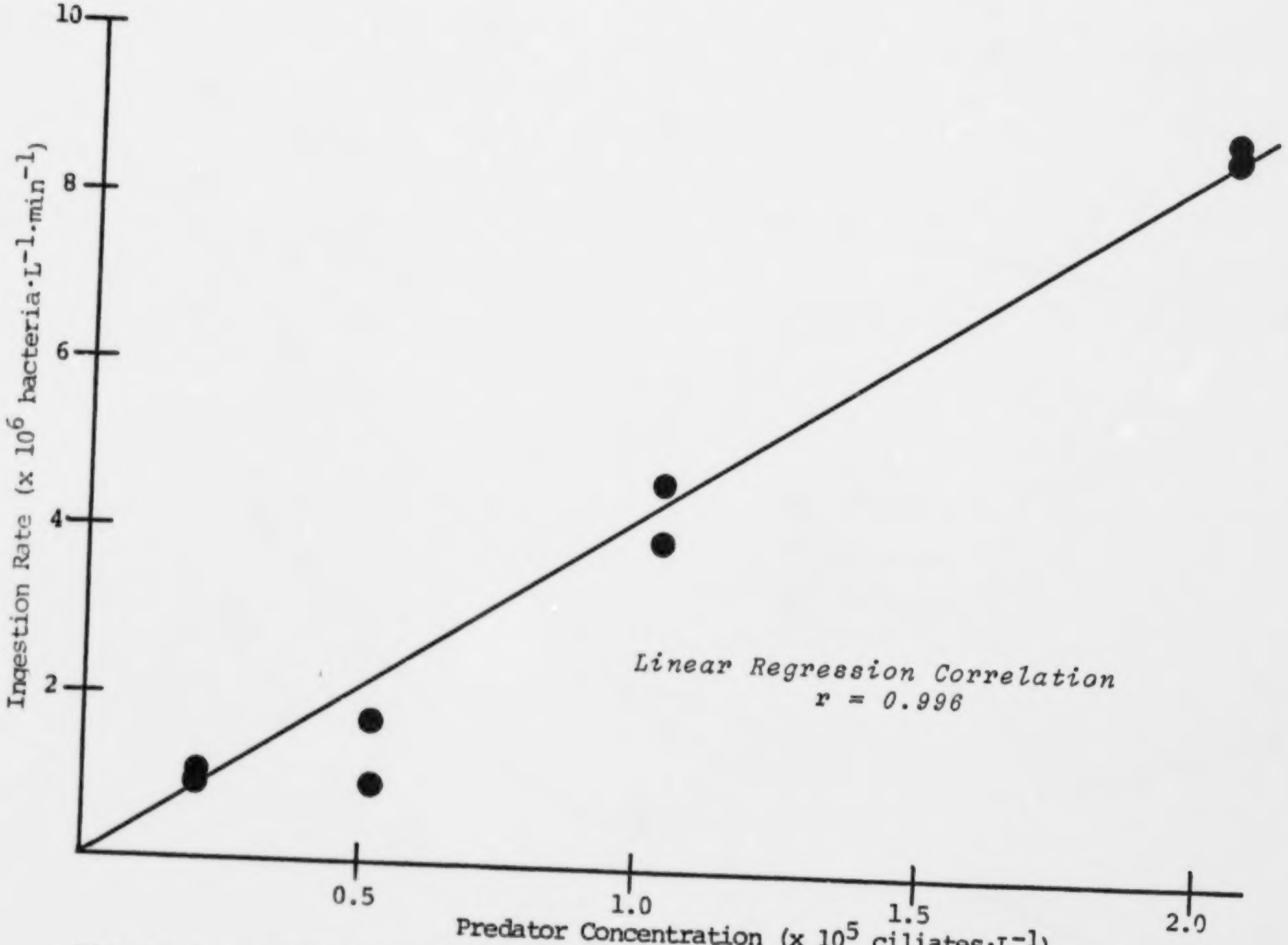


Figure 1. Relationship of the bacterial ingestion rate of the ciliate, *Euplotes* sp. to its population density. Data obtained from laboratory experiments with cultured isolates. Bacterial concentration was constant in all samples (1.3×10^9 cells·L^{-1}).

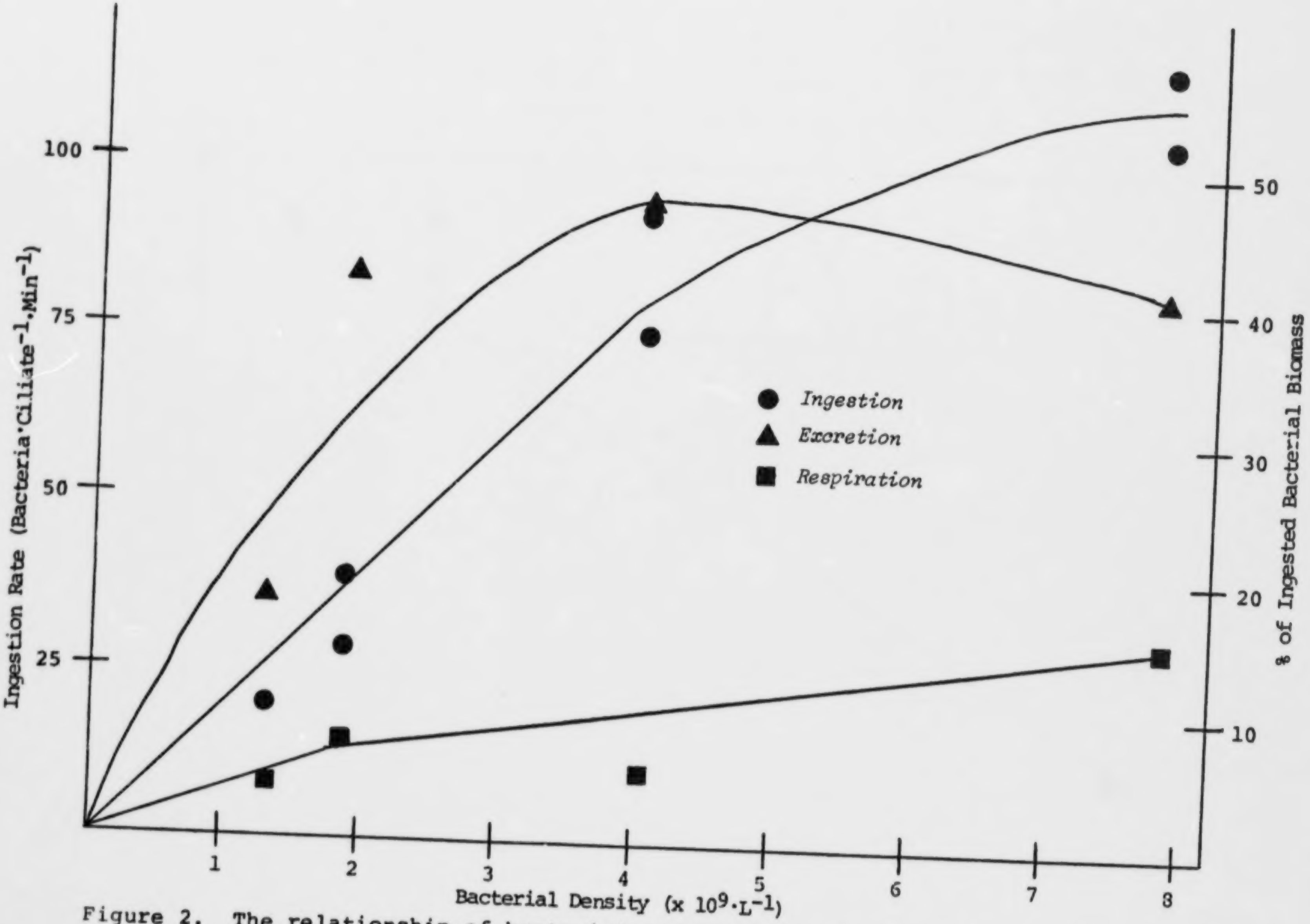
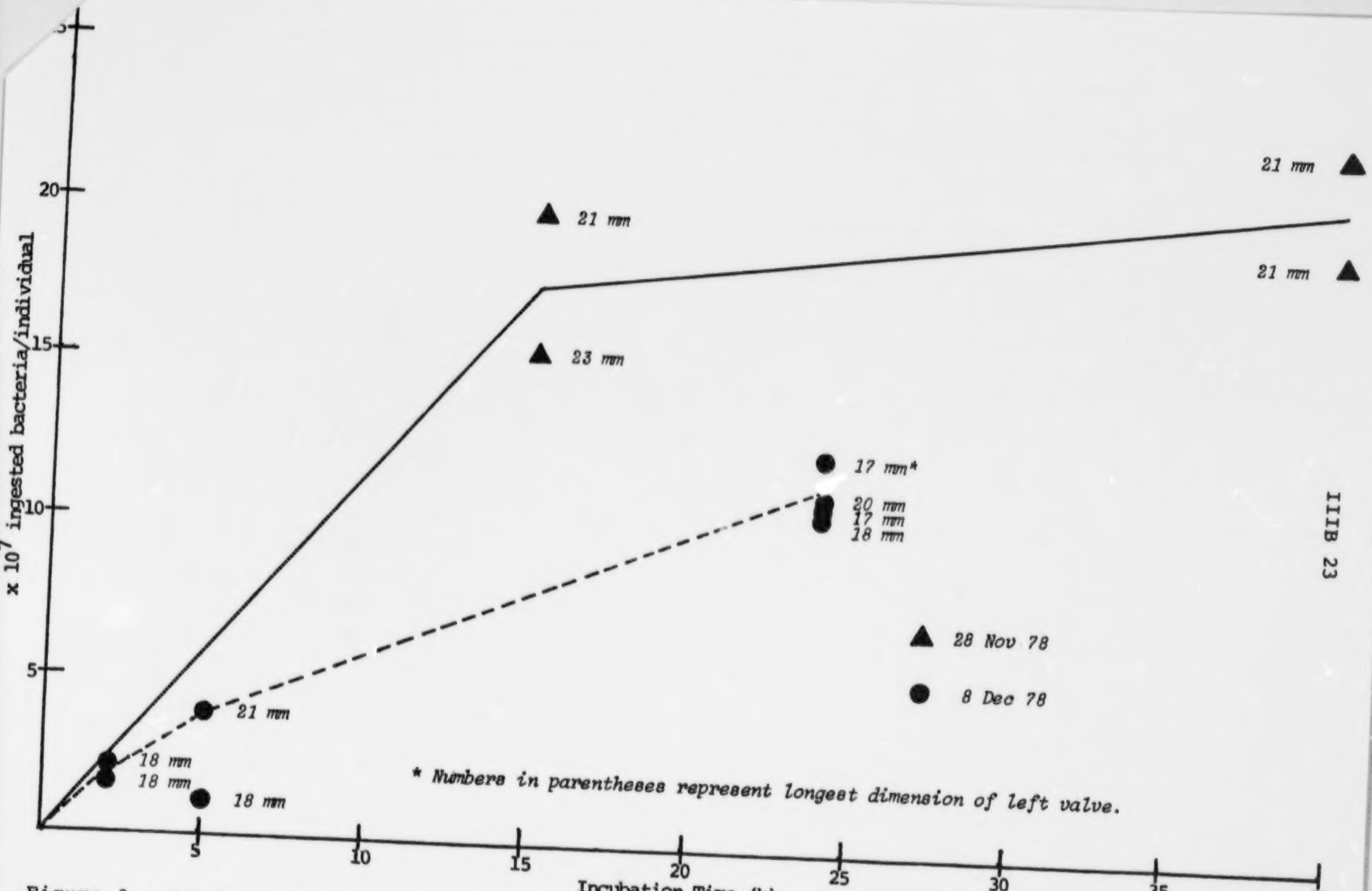


Figure 2. The relationship of bacterial concentration to ingestion, respiration, and and excretion of bacterial biomass by the ciliate, *Euplotes* sp. Data obtained from laboratory experiments with cultured isolates. *Euplotes* sp. *Euplotes* sp. concentration = $1.06 \times 10^5 \cdot L^{-1}$ Forty minute time points used.



* Numbers in parentheses represent longest dimension of left valve.

Figure 3. Metabolically corrected (respiration and excretion) ingestion kinetics of bacteria by *Mytilus edulis*. ▲ and ● represent actual data points and the lines are drawn through the means.

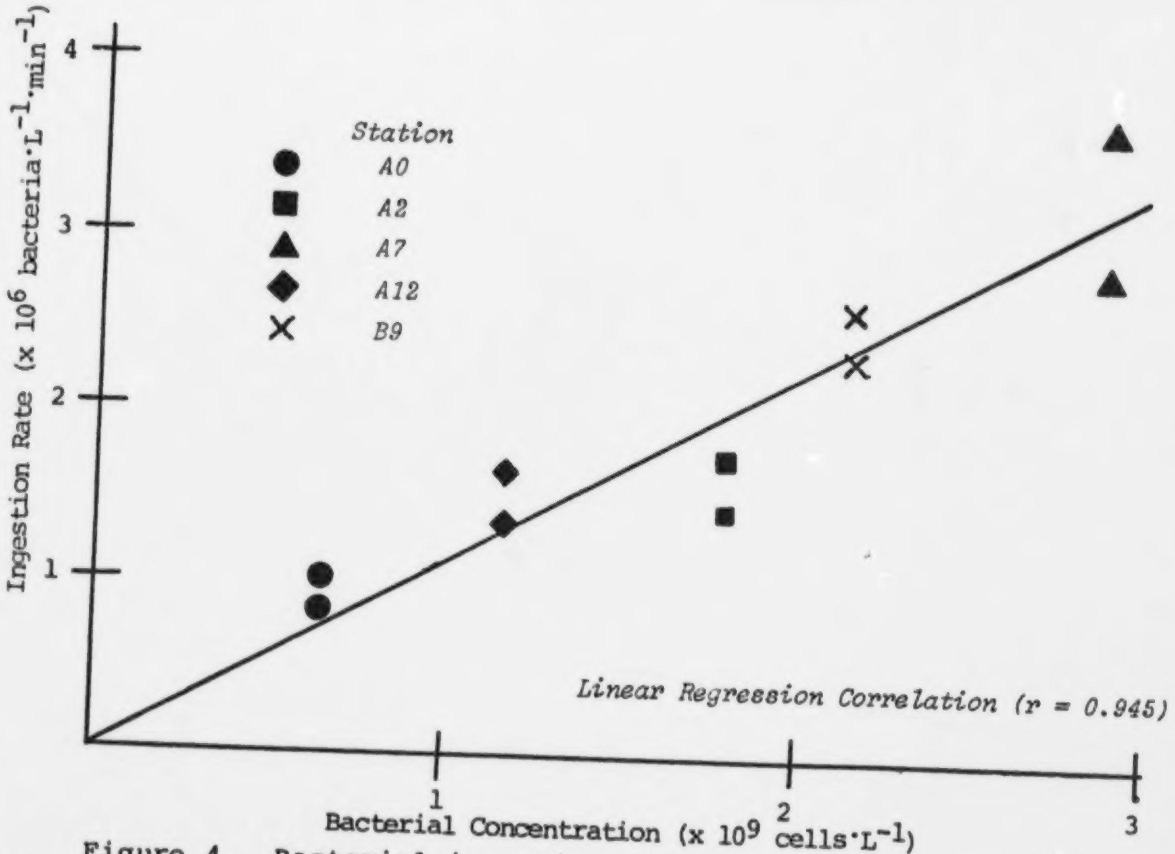


Figure 4. Bacterial ingestion rate of a natural population of bactivorous plankton related to bacterial population density in samples collected from Los Angeles Harbor stations on 2 Aug 78. Points on graph are actual data points. Grazer population density and identity were not determined. Bacterial numbers were determined by means of epifluorescence.

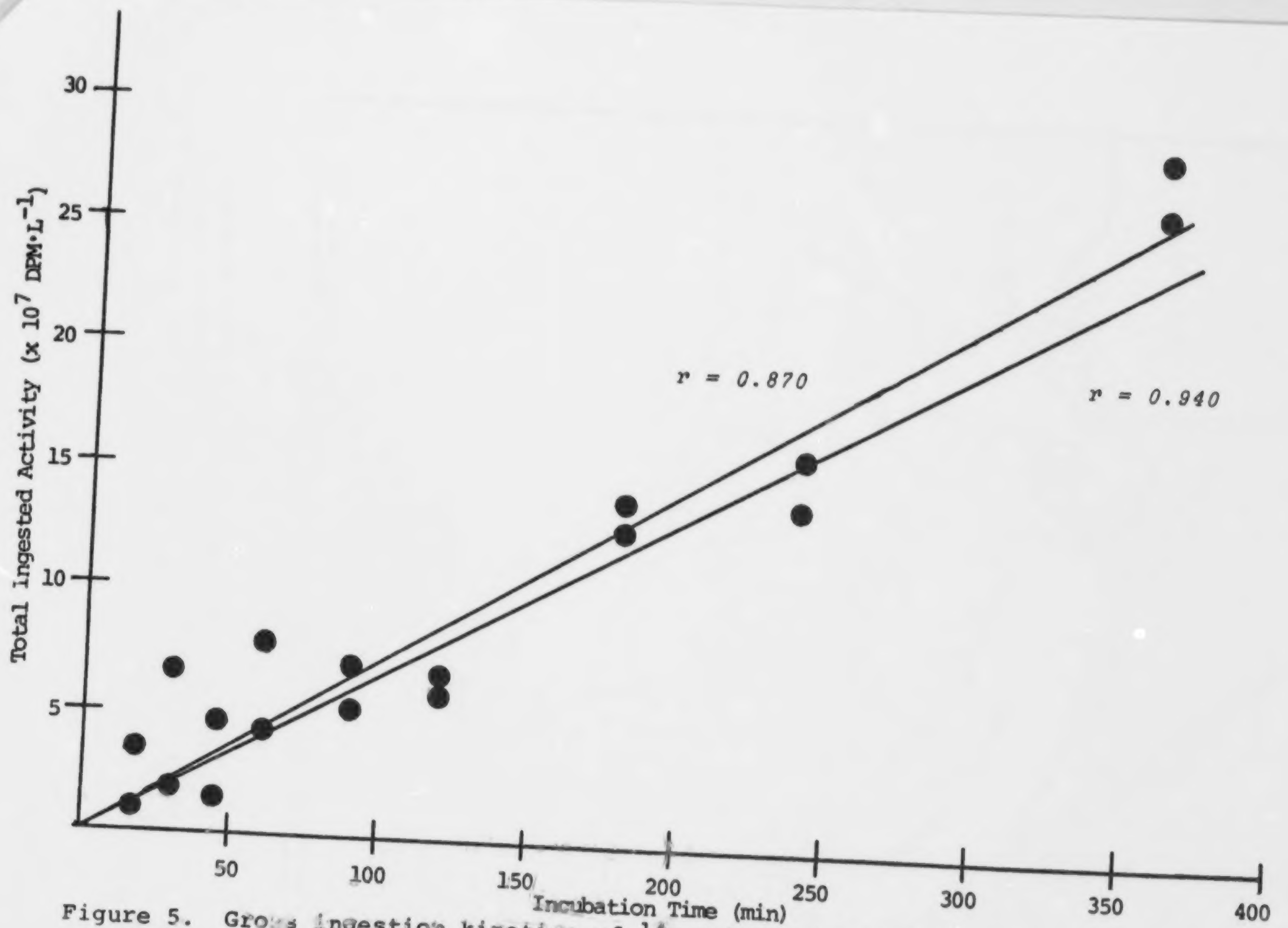


Figure 5. Gross ingestion kinetics of ^{14}C-labeled bacteria by bactivorous plankton (5-203 μm) from Station A2 in Los Angeles Harbor, 2 Aug 78. Points represent actual respiration and excretion corrected ingested activity (DPM). The lower line is a linear regression which doesn't include the 360 min point and the upper line includes all points.

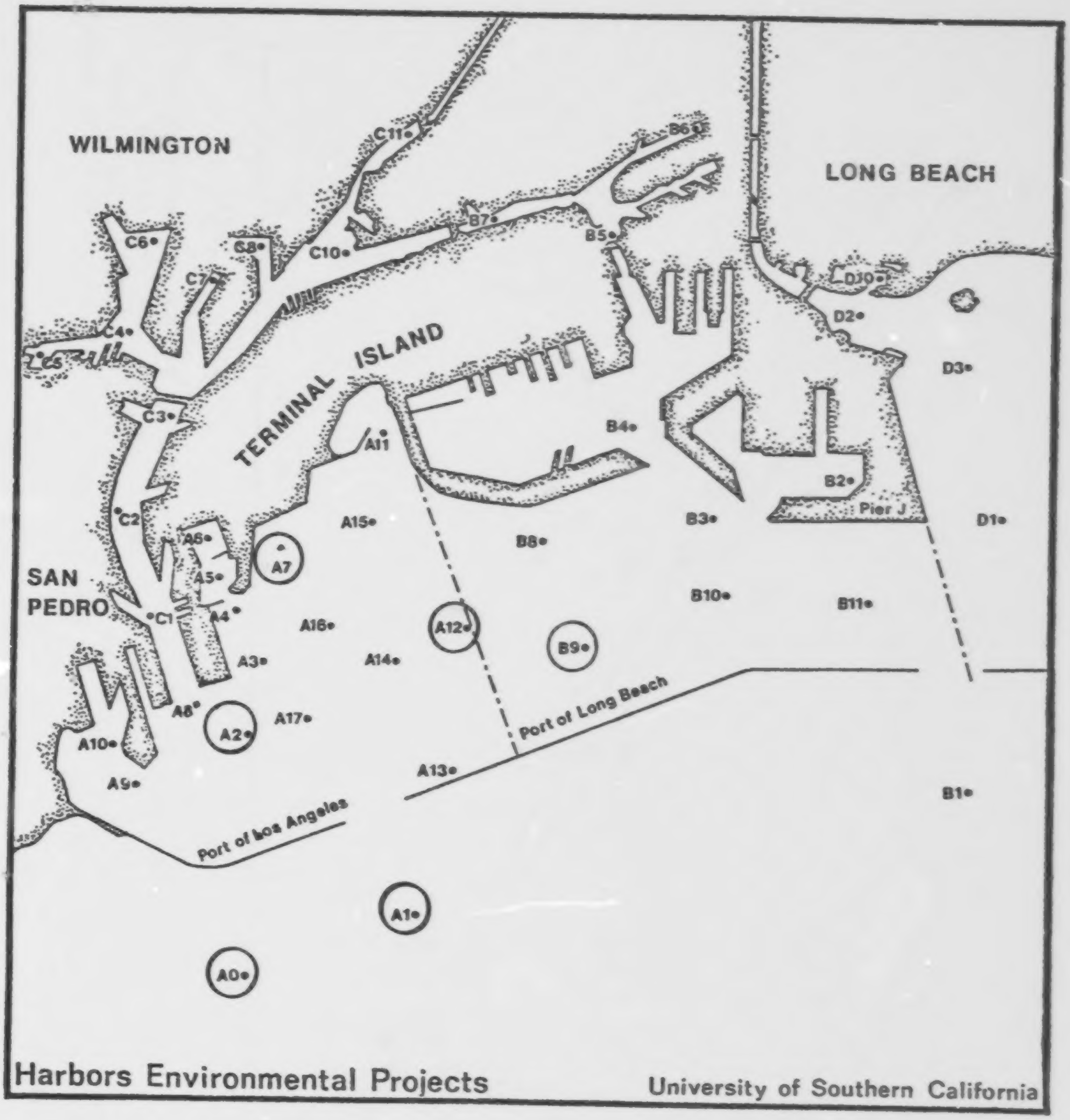


Figure 6. Stations for microbiological sampling in southern California coastal and harbor waters. Not depicted are mid-San Pedro Channel and Santa Catalina Island, Big Fisherman's Cove station.

SEASONAL TRENDS IN TOTAL CHLOROPHYLL *a* DISTRIBUTION AMONG SIZE CLASSES OF PARTICLES IN LOS ANGELES HARBOR, OCTOBER 1977-DECEMBER 1978

INTRODUCTION

This study was initiated as one part of a more comprehensive investigation of the microbial activity at four stations in Los Angeles Harbor and one station outside the harbor's breakwater (Figure 1). Since chlorophyll *a* remains an often-used index to the primary productivity and standing stock of a body of water, any such comprehensive investigation would not be complete without consideration of chlorophyll *a*. In this study, it will be used in conjunction with bacterial standing stock, measurements of heterotrophic uptake, ATP, and other parameters.

While seasonal patterns in total chlorophyll *a* at different sites within the harbor and just outside the harbor since 1973 have been described (Oguri, 1974; 1976), this study adds a new dimension to knowledge about chlorophyll *a* in the harbor. The amount of chlorophyll *a* in particles of six size classes has been determined monthly at five stations. Knowledge of the distribution of chlorophyll *a* among these size classes should be valuable in correlating the results of the other parts of this study to the particular groups of phytoplankton.

In an attempt to characterize the nature of these organisms further, floristic analysis was made. For each station at each month, the species composition and cell numbers were determined. All of the data available should give a better picture of the phytoplankton activity of Los Angeles Harbor and southern California coastal waters than has been possible previously.

MATERIALS AND METHODS

Samples were collected from the five stations at 1 m depth in sterile Niskin samplers. Samples were kept in coolers in darkness until their return to the laboratory. All samples were filtered within seven hours of their collection.

In all, five different poresize filters (Nuclepore) were used. Aliquots of the sample were filtered under <5 mm Hg vacuum through the following filters: 0.2 µm; 0.6 µm; 1.0 µm; 5.0 µm; 10 µm. In addition, a 37 µm screening material (Nitex) was used in December 1978. Filters were placed in 10 ml of 90%

acetone and samples were permitted to extract for 24 hours in darkness and under refrigeration. Before analysis, samples were allowed to reach room temperature in the dark. Chlorophyll *a* was determined by the fluorometric method of Yentsch and Menzel (1963) and Holm-Hansen, *et al.* (1965) using a Turner model 111 fluorometer. The convention of describing a size fraction, x, is as follows: size fraction x is greater than 0.2 µm but less than 0.6 µm. In symbols this is displayed: size fraction $0.2\ \mu m < x < 0.6\ \mu m$.

The amount of pigment contained in the following size classes was determined by difference from total chlorophyll *a*: $0.2 < x < 0.6$; $0.6 < x < 1.0$; $1.0 < x < 5.0$; and $\bar{x} > 5.0\ \mu m$. Total chlorophyll *a* was defined as the amount of chlorophyll *a* retained by a 0.2 µm poresize filter. In October 1978, an experiment was carried out to determine if, in fact, the amount of chlorophyll *a* retained by a 0.2 µm poresize filter truly represents total chlorophyll *a*. An Amicon high-presssure, flow through filter holder was used. A seawater sample from A2 which had already been filtered through a 0.2 µm poresize filter was forced through a filter of 10,000 molecular weight retention. Pressure was supplied by nitrogen gas, and the sample was stirred by a magnetic stir bar. A 38-fold concentration of the original sample was attained. Chlorophyll *a* was extracted by phase separation and quantified by the fluorometric method.

In August 1978 water samples were collected from 1, 3, 6, 9 and 12 m at station A2. These samples were analyzed for total chlorophyll *a* and the distribution of chlorophyll *a* among size classes of particles was determined as described above. In November 1978, this procedure was repeated for a station at the black buoy west of the reef kelp bed at the Isthmus at Santa Catalina Island. At this station, samples were taken from depths of 1, 10, 20, 30 and 40 m.

Floristic data were collected by Greg Morey-Gaines and Roseann Ruse. Samples were collected, preserved and stained with Lugol's iodine solution. Observation and counts were made with a settling chamber and inverted microscope.

RESULTS

The chlorophyll *a* data collected are summarized on a monthly basis. The data are incorporated in the figures. Unless indicated otherwise, all values represent the average of two replicates. The inherent reproducibility of the fluorometric technique is about 8% (Kiefer, personal communication), and the average value for all samples in this study is 5%. In the calculation of the data for "% of total passing" and "% of total" chlorophyll *a* in a given size class, error estimates are presented as "± x." These values are not statistical limits, or standard deviations. They represent the propagation of the inherent 8% error in the analytical technique through the calculations of the values for each column.

Text Table 1 summarizes the results of an experiment conducted on October 4, 1978 on an A2 sample. The experiment was designed to determine if, in fact, the chlorophyll *a* retained by a 0.2 μm poresize filter really represents total chlorophyll *a* of a sample. As stated in this table, that pigment which passes a 0.2 μm poresize filter, but is retained by a 10,000 molecular weight filter represents only 0.07% of all pigment contained in particles of greater than 10,000 molecular weight.

Text Table 1
Results of experiment to determine if the amount of chlorophyll *a* retained by a 0.2 μm poresize filter really represents "total" chlorophyll *a* of a sample.

1) "Total" chlorophyll *a* retained by a 0.2 μm poresize filter:	6.46 $\mu g \cdot l^{-1}$
2) Chlorophyll *a* passing a 0.2 μm filter, but trapped on 10,000 molecular weight Amicon filter:	Sample 1 0.0049 $\mu g \cdot l^{-1}$ Sample 2 0.0037 $\mu g \cdot l^{-1}$
3) % of total (6.46 + 0.0043 $\mu g \cdot l^{-1}$) passing a 0.2 μm poresize filter, but retained by a 10,000 molecular weight filter:	0.07%

Seasonal patterns

Seasonal patterns in total chlorophyll *a* concentration at each station are shown in Figure 2. Station A0 has a relatively low chlorophyll *a* concentration over most of the year, with values of <4 $\mu g \cdot l^{-1}$ chlorophyll *a*. The only feature of note is the July peak of 15.60 $\mu g \cdot l^{-1}$. This burst of chlorophyll *a* was short-lived with the values for August through November 1978 near baseline levels.

Station A2 also shows mid-summer concentrations of chlorophyll *a* that are much higher than the rest of the year. The July 1978 peak was 15.84 $\mu g \cdot l^{-1}$. Evidence for a spring burst in chlorophyll *a* exists. The March 1978 value of 6.39 $\mu g \cdot l^{-1}$ is well above baseline levels of about 5 $\mu g \cdot l^{-1}$. The spring peak is impossible to define temporally since February and March data for 1978 are missing, but high levels are maintained from July through September 1978.

Both the April spring peak and the July 1978 summer peak are evident in station A7. In April, the concentration of chlorophyll *a* reached 9.84 $\mu g \cdot l^{-1}$ and in July the value was 22.32 $\mu g \cdot l^{-1}$. Note that baseline levels are about 3-5 $\mu g \cdot l^{-1}$ of chlorophyll *a*. At station A7 the July peak was short-lived, as at station A0.

Stations A12 and B9 are extremely similar -- not only in their temporal patterns, but also in the amplitudes of the peak chlorophyll *a* concentrations. The sampling of these stations began in April of 1978. A hint of a spring peak like that seen in stations A7 and A2 exists. April values drop to about 3 $\mu g \cdot l^{-1}$ in May and rise slightly in June before rising sharply in July. The July peak present at A0, A2 and A7 is also present at A12 and B9. At A12 the July chlorophyll *a* concentration is 21.78 $\mu g \cdot l^{-1}$ and at B9 it is 19.08 $\mu g \cdot l^{-1}$. Both stations show a precipitous drop in chlorophyll *a* at the time of the August 1978 sampling. The August value for station A12 was 4.65 $\mu g \cdot l^{-1}$ chlorophyll *a*. That for station B9 was 3.80 $\mu g \cdot l^{-1}$. The September 1978 values nearly equaled those of July -- 21.58 $\mu g \cdot l^{-1}$ for A12 and 18.03 $\mu g \cdot l^{-1}$ for station B9. Following September, values at both stations again dropped to lower levels and show a slight increase from October through December 1978.

Vertical profiles

A vertical profile of chlorophyll *a* is shown in Figure 3 for station A2 on August 16, 1978. A subsurface chlorophyll *a* maximum is indicated at the 3 m depth. The concentration of chlorophyll *a* at 3 m is 12.30 $\mu g \cdot l^{-1}$. Chlorophyll *a* concentration decreases with increasing depth to a value of 0.466 $\mu g \cdot l^{-1}$ at 12 meters.

A similar profile for Isthmus Cove at Catalina Island is presented in Figure 4. A subsurface chlorophyll *a* maximum is indicated at 10 m -- a value of 0.68 $\mu g \cdot l^{-1}$. Concentration of chlorophyll *a* decreases with increasing depth to a value of 0.11 $\mu g \cdot l^{-1}$ at 40 m.

Size fractionation

After calculation of the amount of chlorophyll *a* present in the various particle size classes, the data were represented as bar graphs in Figures 5-17. Throughout the first three months of sampling, October 1977, November 1977 and January of 1978, the >5 µm size class contained more than 50% of the total chlorophyll *a* (Figures 5-7). In April 1978, at stations A0, A2, A7 and B9, the >5 µm size class only accounted for 22-36% of total chlorophyll *a*. The size class of particles between 1 µm and 5 µm assumed more importance at A0, A2 and A7 with 43%, 56% and 68% of total chlorophyll *a* in the >5 µm size class (Figure 8).

DISCUSSION

The results shown in Text Table 1 demonstrate that the practice of designating the chlorophyll *a* retained by a 0.2 µm filter as "total" chlorophyll *a* is probably valid. In October of 1978, only 0.07% of chlorophyll *a* contained in particles of greater than 10,000 molecular weight was contained in particles less than 0.2 µm. While it is true that this was done only for one date and one station (A2), it is unlikely that the results would change by more than one order of magnitude. Even so, this would mean that <1% of chlorophyll *a* is in the >10,000 molecular weight particles which pass a 0.2 µm porosity filter.

The seasonal pattern in total chlorophyll *a* at all stations show strong peaks in chlorophyll *a* during the summer. At A0, A7, A12, and B9, this peak reaches high values in July, and drops off drastically in August. At station A2, there is a slight drop off in August, but high values persist until October. Stations A12 and B9 are nearly identical and both show another peak in chlorophyll *a* concentration in September of 1978, with this second peak reaching essentially the same values as the July peak.

An attempt was made to correlate the amount of chlorophyll *a* over time to the number of phytoplankton cells present as determined by direct count methods (Greg Morey-Gaines, personal communications). However, the floristic data are incomplete, and any analysis made at this time is to be regarded with caution. Cell numbers of phytoplankton in March 1978, April 1978, and May and June 1978 at station A2 were 314/ml, 4,851/ml, 4089/ml and 3,135/ml, respectively. Because these data for chlorophyll *a* are missing for March of 1978 at A2, the trends cannot be considered parallel. In addition, values of chlorophyll *a* dropped from 12.36 $\mu g \cdot l^{-1}$ to 6.39 $\mu g \cdot l^{-1}$ between April and May while cell numbers remained nearly constant. The decrease in cell numbers from 4,089 per ml in May to 3,135 per ml in June was accompanied by a decrease in chlorophyll *a* from 6.39 $\mu g \cdot l^{-1}$ in May to 4.61 $\mu g \cdot l^{-1}$ in June 1978.

Another disparity is seen at station A12. In April 1978, cell numbers were 2,117 per ml, but 2,521/ml in June 1978. The chlorophyll *a* values differ greatly: 13.92 $\mu g \cdot l^{-1}$ for April and 3.73 $\mu g \cdot l^{-1}$ in June.

From these limited data, it would appear that cell numbers and chlorophyll *a* probably are not directly correlated. Changes in species composition could alter the chlorophyll *a*/cell ratio and obscure such a relationship.

There are indications in the floristic data of drastic changes in flora within a month. In March, April and May of 1978, three species of the diatom *Chaetoceros* comprised over

80% of the total cell count at all stations. In June of 1978, flagellates of 5 µm or larger made up at least 44% of the number of phytoplankton cells. At station A0, this value was 67%. It is tempting to speculate that the spring peak in chlorophyll *a* reported for stations A2, A7 and probably A0 was due to the dominance and presence of these diatoms. It is impossible at this point to determine if the flagellate-dominated flora was the reason for the July peak of chlorophyll *a* found at every station since floristic data for July aren't available. The very sharp increase in chlorophyll *a* is suggestive of very rapid increases in cell numbers of a dominant form. Small flagellates, with their rapid rates of cell division are likely candidates, but this cannot be confirmed.

It should be possible to use size fractionation data to help determine what type of autotrophs are dominant. However, most of the data for this first year do not permit such an analysis. We have already seen that most chlorophyll *a* is in the >5 µm size class. However, it is necessary to further subdivide this class in order to make any decisions about dominant forms from this type of data. A step in this direction has been made in adding 10 µm and 37 µm filters to our routine sampling for chlorophyll *a*.

From May through October 1978, the >5 µm size class resumed importance. During May, no less than 50% of total chlorophyll *a* was found in this class (Figure 9). During June, even a greater percent of total chlorophyll *a* occurred in this size class -- 63%, 70%, 71% and 76% for stations A12, A7, A2 and A0, respectively (Figure 10). July was much the same. From 67-96% of total chlorophyll *a* occurred in particles greater than 5 µm (Figure 11). Stations inside the harbor had 59-74% of total chlorophyll *a* in particles >5 µm in August. However, at station A0 - outside the harbor - the total pigment was nearly equally divided among three size classes: >5 µm; $1 < x < 5$ µm; and $0.2 < x < 0.6$ µm (Figure 12). September and October of 1978 demonstrate this same trend - greater than 47% of total chlorophyll *a* occurred in particles >5 µm (Figures 13 and 14).

In November, a 10 µm poresize filter was added to the array of filters used in size fractionation. The further resolution of the >5 µm size class for November is shown in figure 15. Now we see that the $1 < x < 5$ µm size class contains the greatest percentage of the total pigment, in most cases. From 40-51% of total chlorophyll *a* was in this size class for stations A0, A2, A7, A12. At all stations, the percent in the $5 < x < 10$ µm and >10 µm size classes was about equal.

In December 1978, even greater resolution was obtained by adding a 37 µm filtering material to the filtering regime (Figure 16). The size class of particles between 10 and 37 µm was most dominant at A0 and A2. At other stations, the pigment was more evenly distributed among the size classes. For this month, the $x > 37$ µm size class was not a major contributor to chlorophyll *a*.

While the August vertical profile at A2 and the November vertical profile at Isthmus Cove are not represented with bar graphs, the distribution of chlorophyll *a* among the size classes can be compared. At A2, the pattern for each depth is much the same as that for each station in August. At 3, 6, 9, and 12 m, >40% of total chlorophyll *a* was contained in particles >5 µm. At 1 m depth, only 27% was in this size class. The November profile is very different. Chlorophyll *a* seemed more evenly distributed among the size classes. At 1 m, 58% of chlorophyll *a* occurred in particles >10 µm. However, at depths below 1 m, this value declined. In the range from 10-30 m depth, the distribution was quite even. At 40 m depth, there appeared to be no pigment in particles <1 µm.

Figure 17 shows seasonal changes at a single station, B9.

Floristics

Floristic data demonstrate several notable features. The spring months of April and May are marked by high numbers of the diatom *Chaetoceros socialis* and several other *Chaetoceros* species. *Chaetoceros* and the dinoflagellate *Gonyaulax polyedra* were dominant at all five stations in April and at A12 in May (only A2 data are available for May). In June we found numerical dominance by unidentified flagellates of <5 µm. However, *G. polyedra* continued to be very important to total cell carbon present at harbor stations. *Gymnodinium splendens*, another dinoflagellate, was present at A7.

The July samples were dominated numerically, and in terms of carbon, by a diatom *Nitzschia seriata*. At A0 only did flagellates of <5 µm outnumber *N. seriata*. In August we see a variety of species present in the harbor with no real dominance by any one. At A0, however, the diatom *Leptocylindrus danicus* was the most important organism, accounting for >96% of cell number, volume, and carbon. Inside the harbor, *L. danicus* was present at A7, A12 and B9. After their nearly total absence in July, the dinoflagellates *G. polyedra* and *G. splendens* did appear at A2, A7 and A12 in August. However, September was definitely dominated by dinoflagellates. At all stations, *G. polyedra* and *G. splendens* were the most important phytoplankters present.

November appears to be a transition time for the flora. Some *G. polyedra* is still important at A0 and A2. However, the small flagellates have reappeared in greater numbers - in fact, they are the most abundant phytoplankter at all stations. *Leptocylindrus danicus* is important at all harbor stations, but not at A0. A0 has the dinoflagellate *Ceratium furca* as an important contribution to volume and carbon.

The December 1978 flora resemble no other month's flora.

Chaetoceros species and *Ceratium* species are most important. A2 and A7 have large numbers of the diatom *Rhizosolenia*.

Another apparent switchover occurs in January 1979. These samples were dominated both numerically, and to a great extent, in carbon by small, unidentified flagellates.

An attempt was made to correlate the chlorophyll *a* over time with cell number. The coefficient of determination, r^2, was only 0.40. Attempts to correlate chlorophyll *a* concentration with cell volume and cell carbon as estimated from cell volume, resulted in about the same degree of correlation. While poor correlation with cell numbers is not a surprise, the reason for poor correlation with cell carbon is not clear. Perhaps the inherent assumption that cell carbon:chlorophyll *a* ratios are constant is not a good one.

The seasonal trends demonstrated in 1978 in chlorophyll *a* do agree well with those reported by Oguri (1974; 1976) for Los Angeles Harbor. The spring and summer peaks seem characteristic, both in timing and in relative amplitude.

At most months, the small scale resolution of our filtering array does not permit much correlation between species present and the size classes of chlorophyll *a*. Most organisms presently identified are very much larger than 5 µm, as reported in the results section, >50% of total chlorophyll *a* is usually found in the particles >5 µm. However, in November of 1978, the further resolution provided by the addition of a 10 µm poresize filter does enable some interpretation. In November, flagellates of <5 µm were important numerically, and in terms of cell carbon. This is reflected in figure 15, which shows that for most stations, the size class of particles between 1 and 5 µm contained a greater percentage of chlorophyll *a* than any other size class. In December 1978, flagellates virtually disappeared. Figure 16 demonstrates the relative unimportance of the $1 < x < 5$ µm size classes during December. The presence of larger diatoms (*Chaetoceros*) and dinoflagellates (*Ceratium*) is reflected in the greater importance of the >10 µm size classes. With continued use of these larger filters, our ability to correlate the flora with the distribution of chlorophyll *a* among size classes of particles should improve.

Station A0 consistently had lower values of chlorophyll *a* concentration than the stations within the harbor. This is not surprising, and in fact, is to be expected. Likewise, the values for chlorophyll *a* at 1 m at Isthmus Cove, 0.43 $\mu g \cdot l^{-1}$, in November 1978 are much lower than 1 m at A0 in November 1978 (0.98 $\mu g \cdot l^{-1}$). Thus, a distance-offshore dilution effect is seen. All stations within the harbor maintained about the same levels of chlorophyll *a*. Stations A12 and B9 are extremely similar in their seasonal pattern and amplitudes - probably because of their physical proximity. A7 demonstrated the highest levels of chlorophyll *a*. The fact that the same seasonal patterns are found at station A0 as at the harbor stations demonstrates that the causative conditions are not unique to the harbor. Conditions in the harbor may enhance the magnitude of the effect.

SUMMARY

The seasonal trends in chlorophyll *a* concentration for phytoplankton of Los Angeles Harbor and adjacent coastal water in 1978 are reported. These data show persistence, in 1978, of patterns reported for harbor waters since 1972 (Oguri, 1974; 1976). The spring peak occurs in April for stations within the harbor. At the one station outside Los Angeles Harbor, the April peak is much less pronounced. The major peak occurred in July when chlorophyll *a* concentrations reached values of >16 $\mu g \cdot l^{-1}$ for all stations. This July peak was associated with a bloom of the diatom *Nitzschia seriata*. Chlorophyll *a* concentrations at stations within Los Angeles Harbor were always greater than those at station A0, outside the harbor. Two stations, A12 and B9, are extremely similar - not only in the trends of chlorophyll *a*, but also in the magnitude of chlorophyll *a* concentrations. This is probably a reflection of their physical proximity (Figure 1).

Fractionation of chlorophyll *a* into the following size classes: $0.2 < x < 0.6$ µm; $0.6 < x < 1$ µm; $1 < x < 5$ µm; and >5 µm for October 1977-October 1978, demonstrated that >50% of the chlorophyll *a* was contained in particles >5 µm. In November 1978 further fractionation demonstrated that greater than half of this amount was, in fact, contained in particles >10 µm. With the addition of a 37 µm poresize filter in December of 1978, even further subdivision was made. Between 15% and 30% of total chlorophyll *a* was found in the size class >37 µm for this month.

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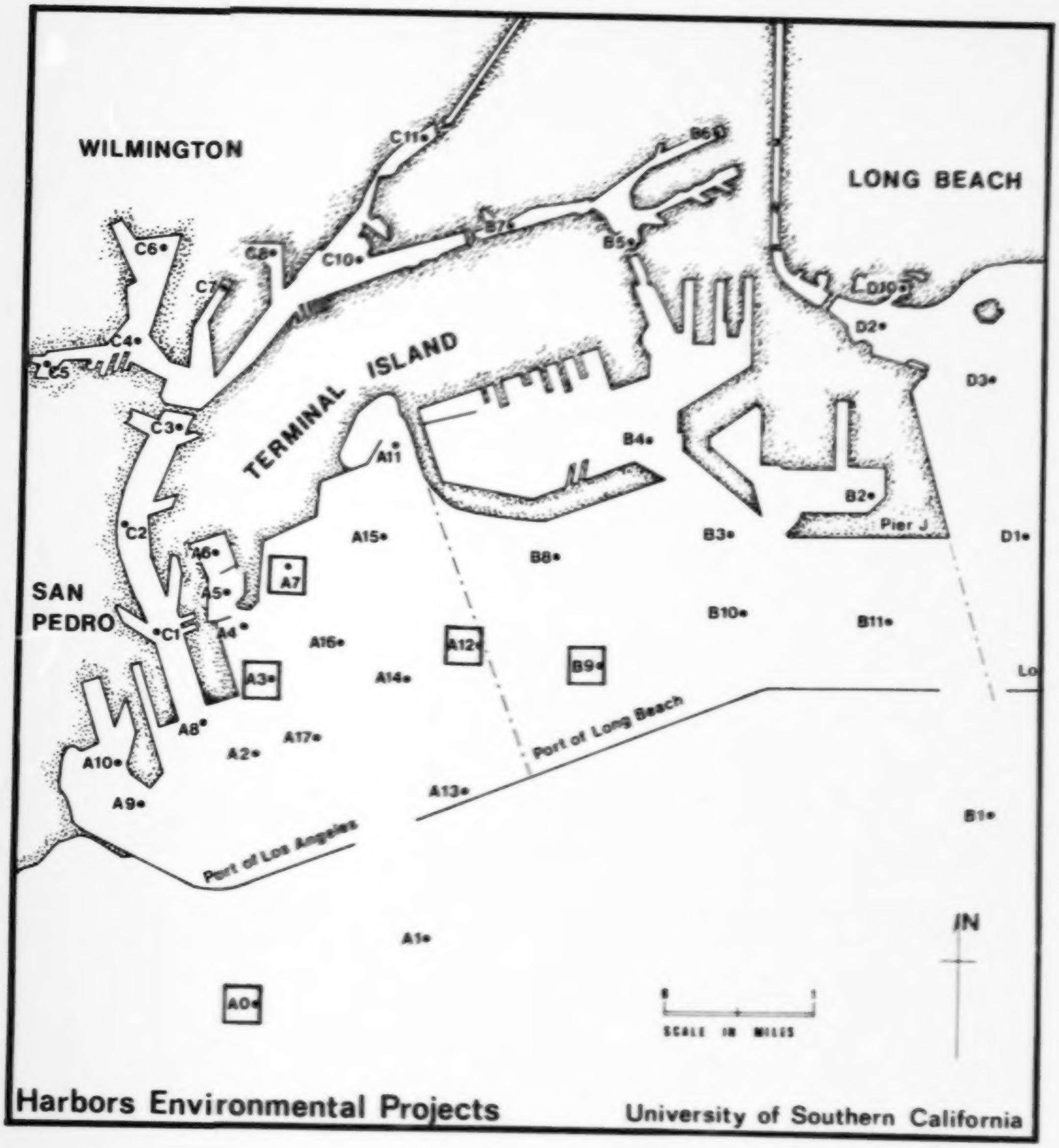

Figure 1. Station locations for chlorophyll *a* and size fractionation studies.

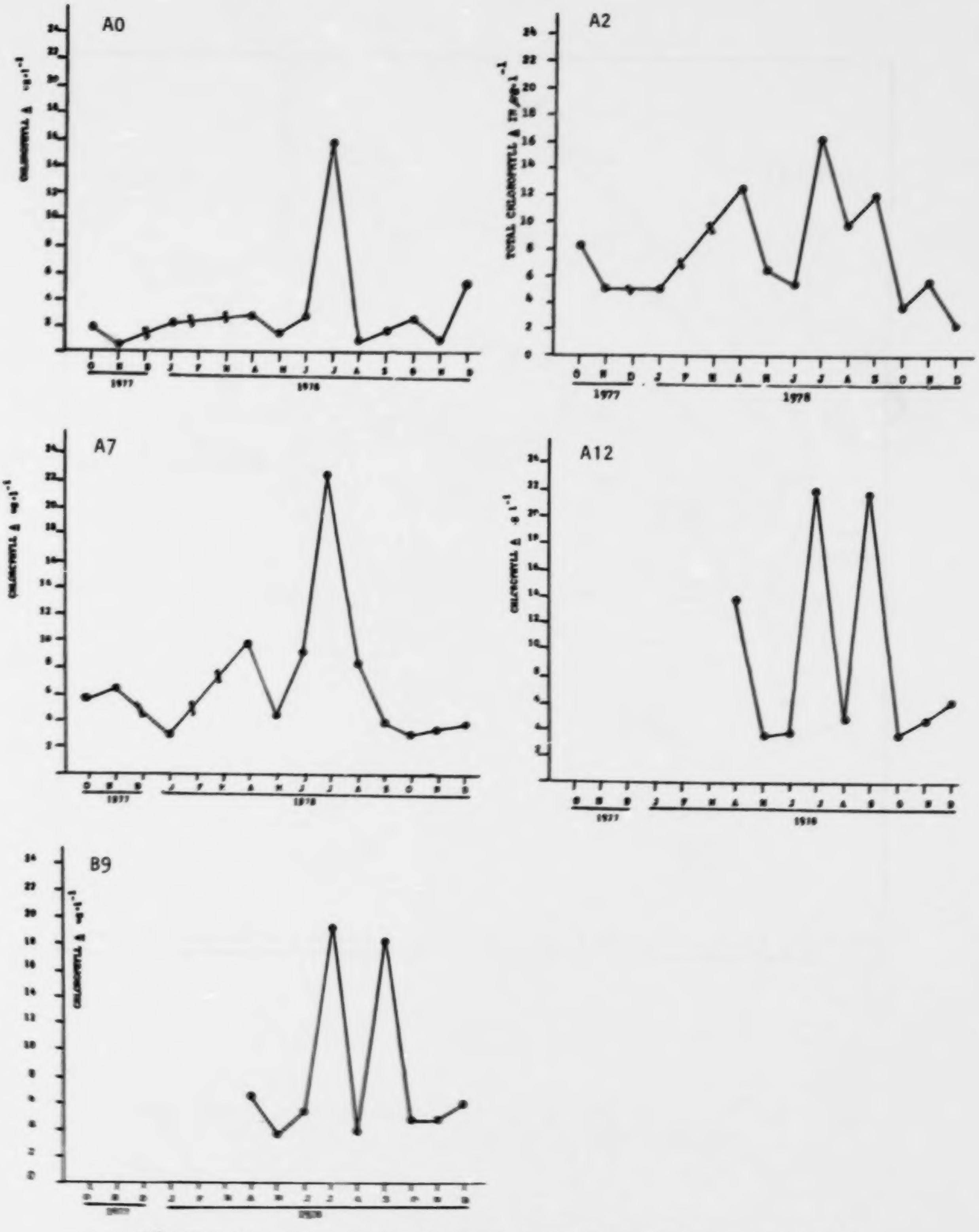

Figure 2. Seasonal changes in chlorophyll *a* at stations A0, A2, A7, A12, and B9.

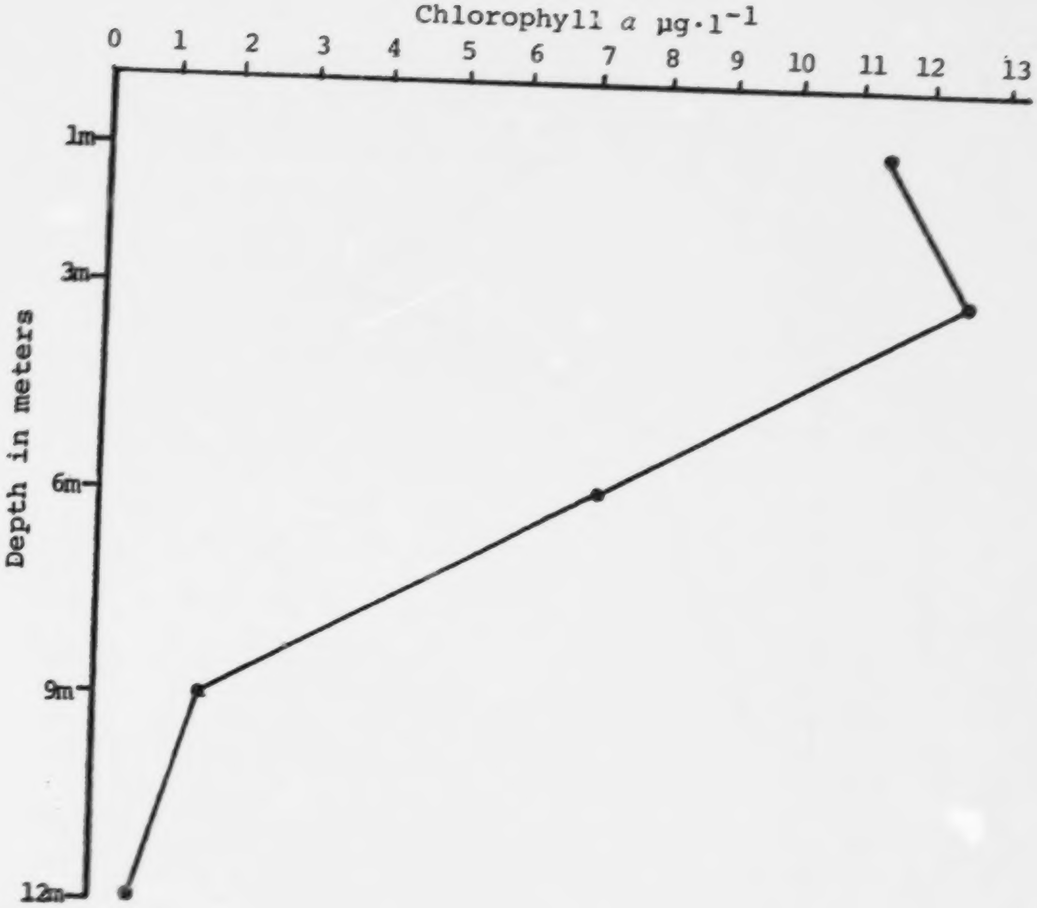

Figure 3. Vertical profile of total chlorophyll *a* concentration at station A2 on August 16, 1978.

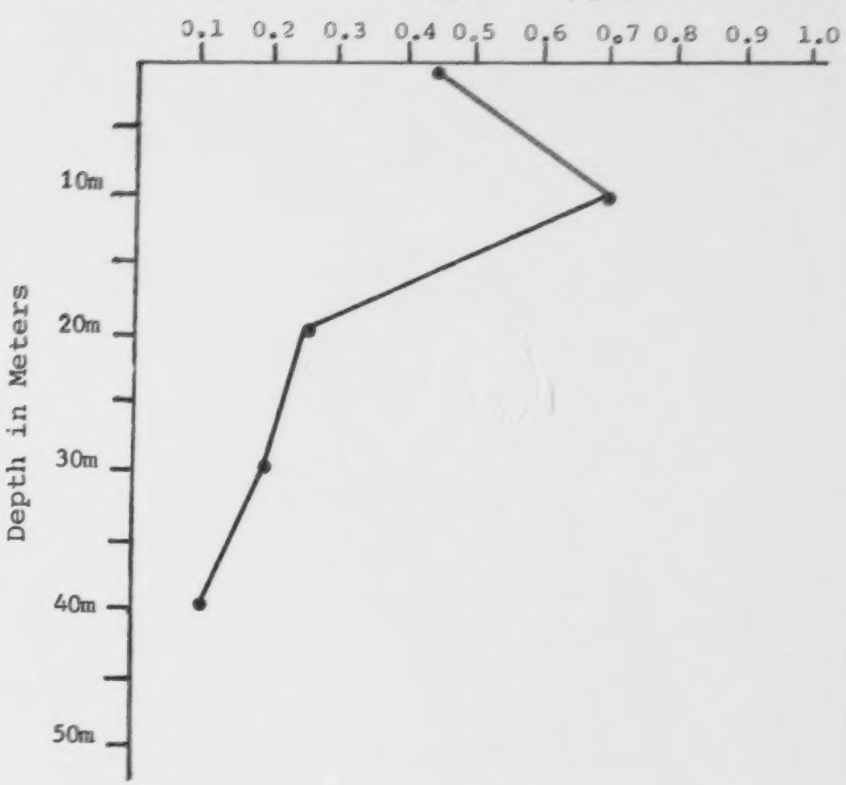

Figure 4. Vertical profile of chlorophyll *a* concentration in Isthmus Cove on November 17, 1978.

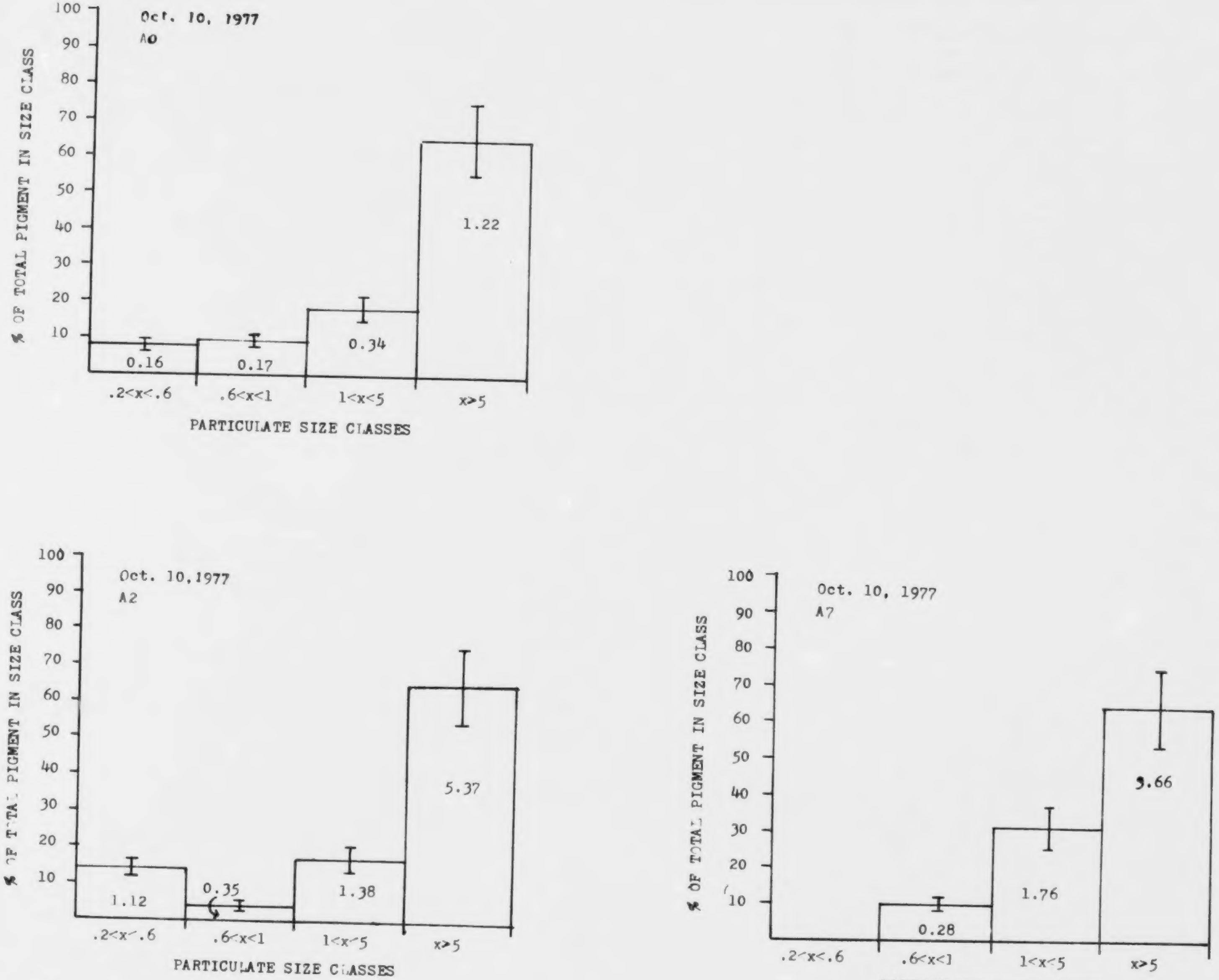

Figure 5. Distribution of chlorophyll *a* among size classes for October 10, 1977 sample.

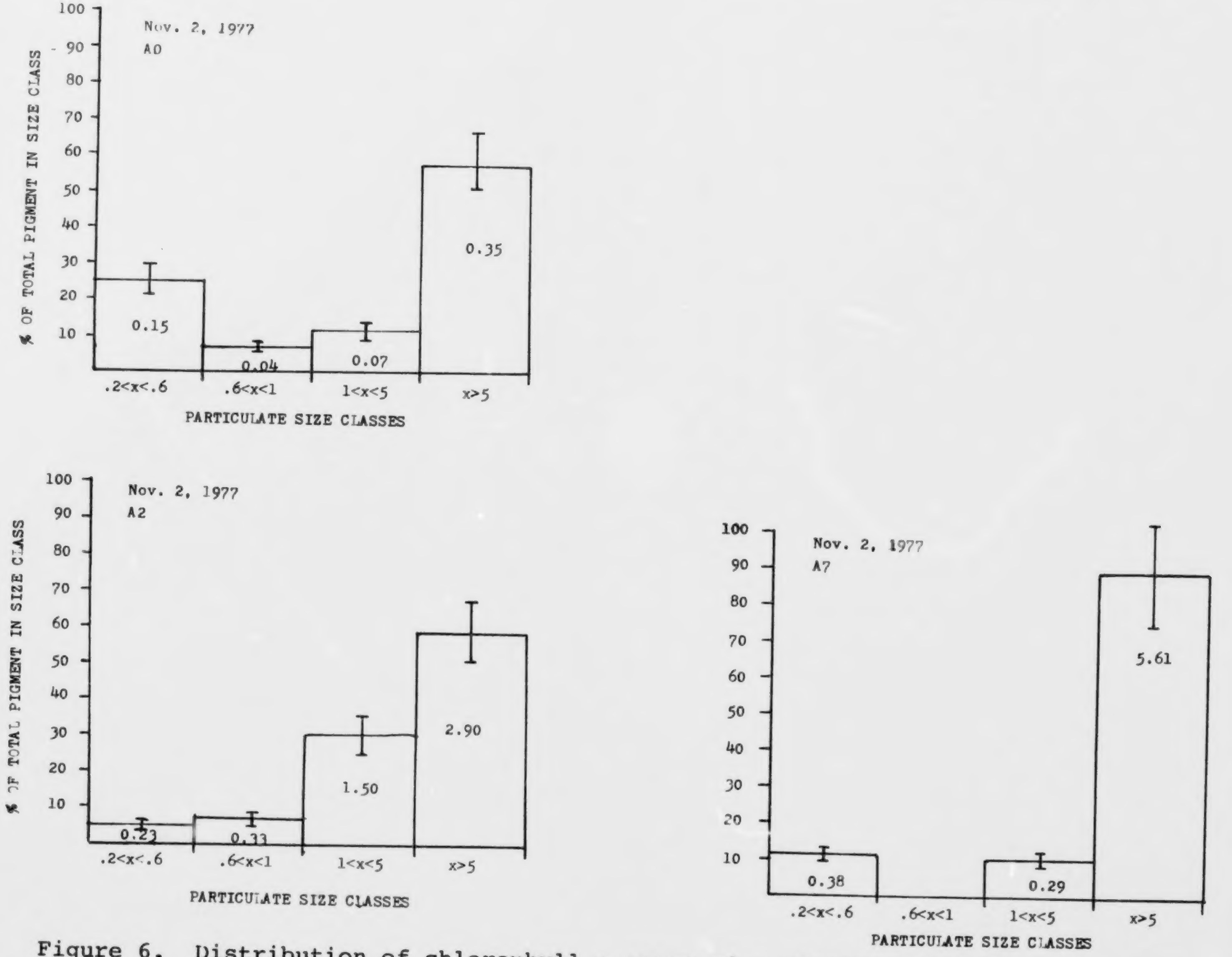

Figure 6. Distribution of chlorophyll *a* among size classes for November 2, 1977 samples.

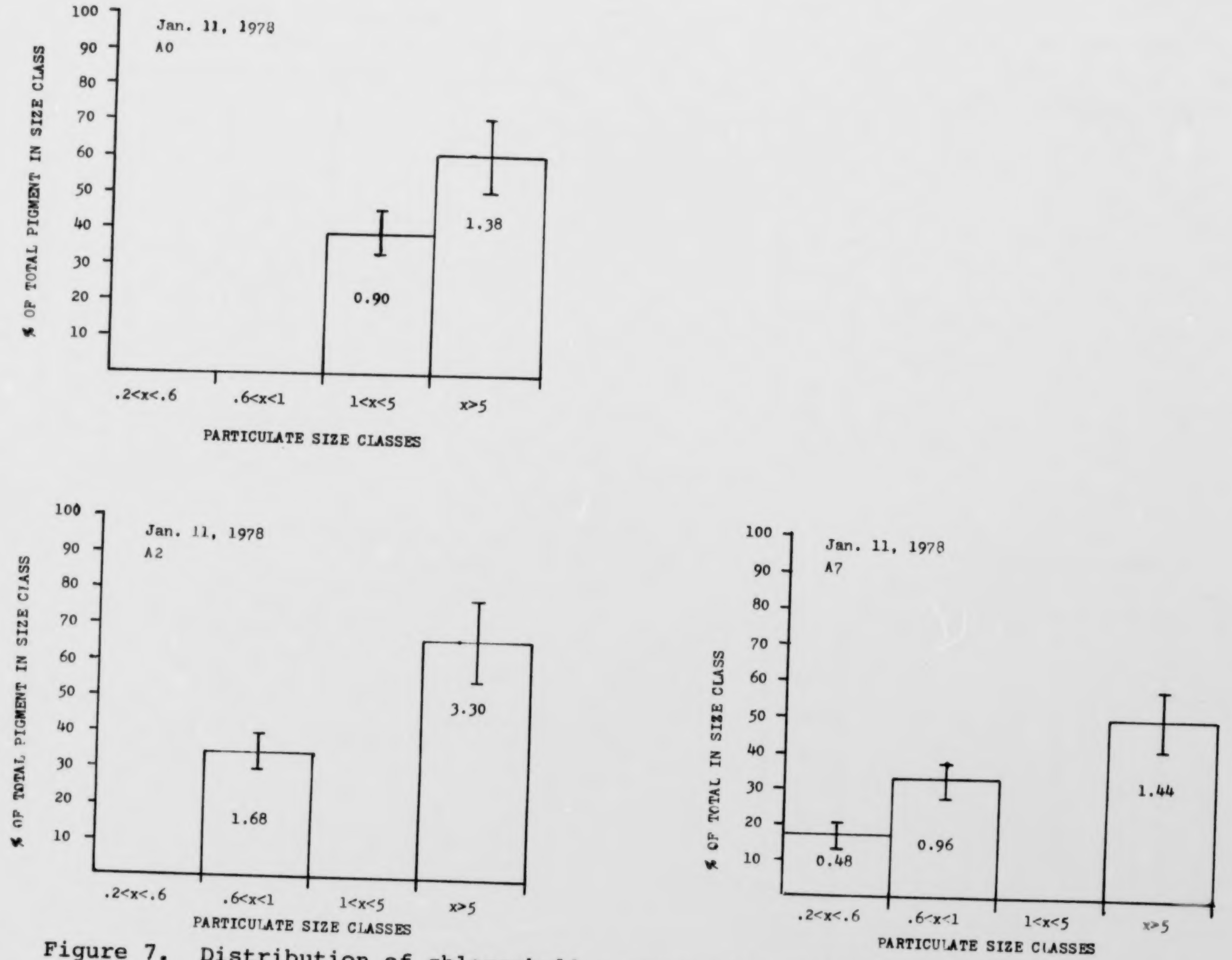

Figure 7. Distribution of chlorophyll *a* among size classes for January 11, 1978 samples.

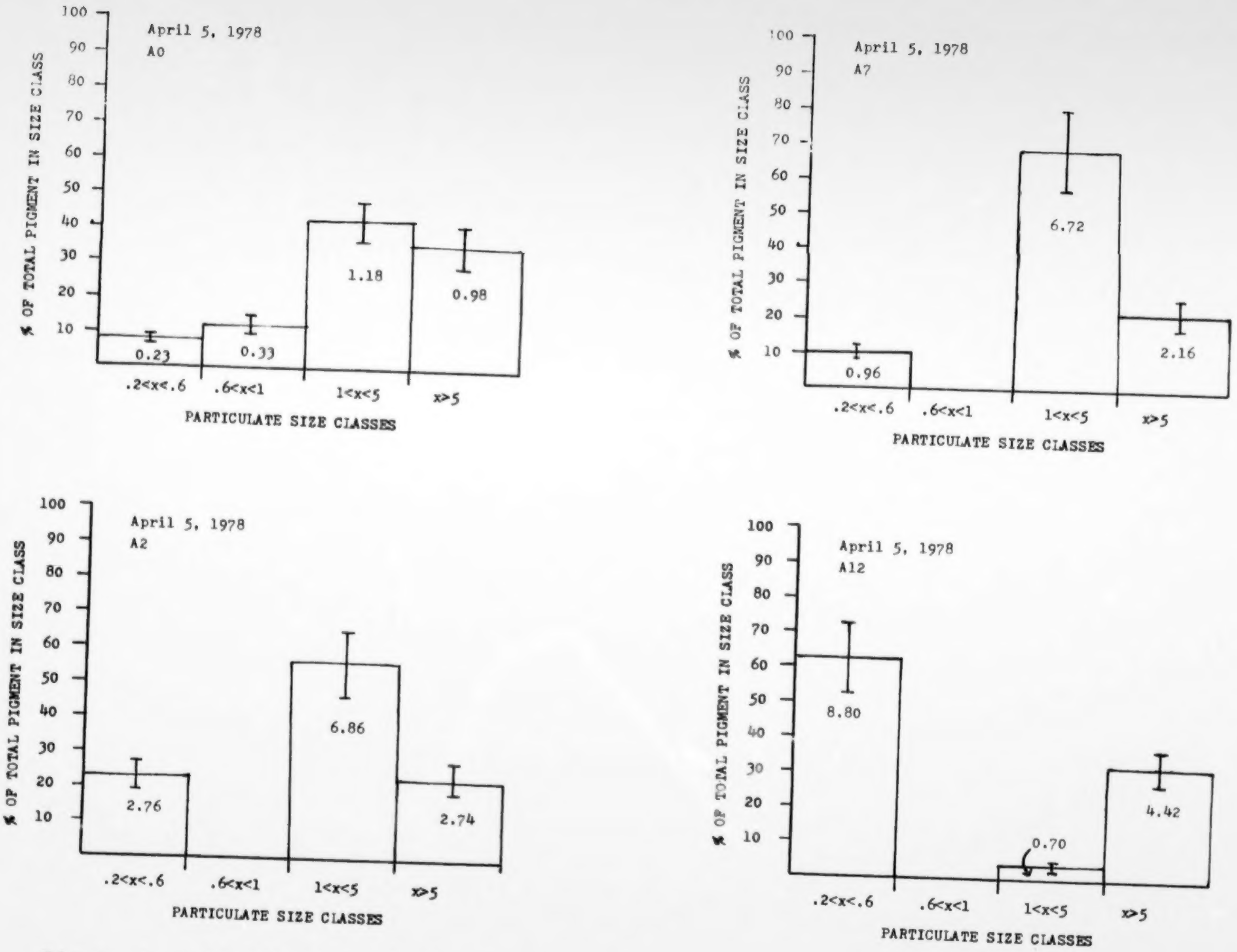

Figure 8. Distribution of chlorophyll *a* among size classes for April 5, 1978 sample.

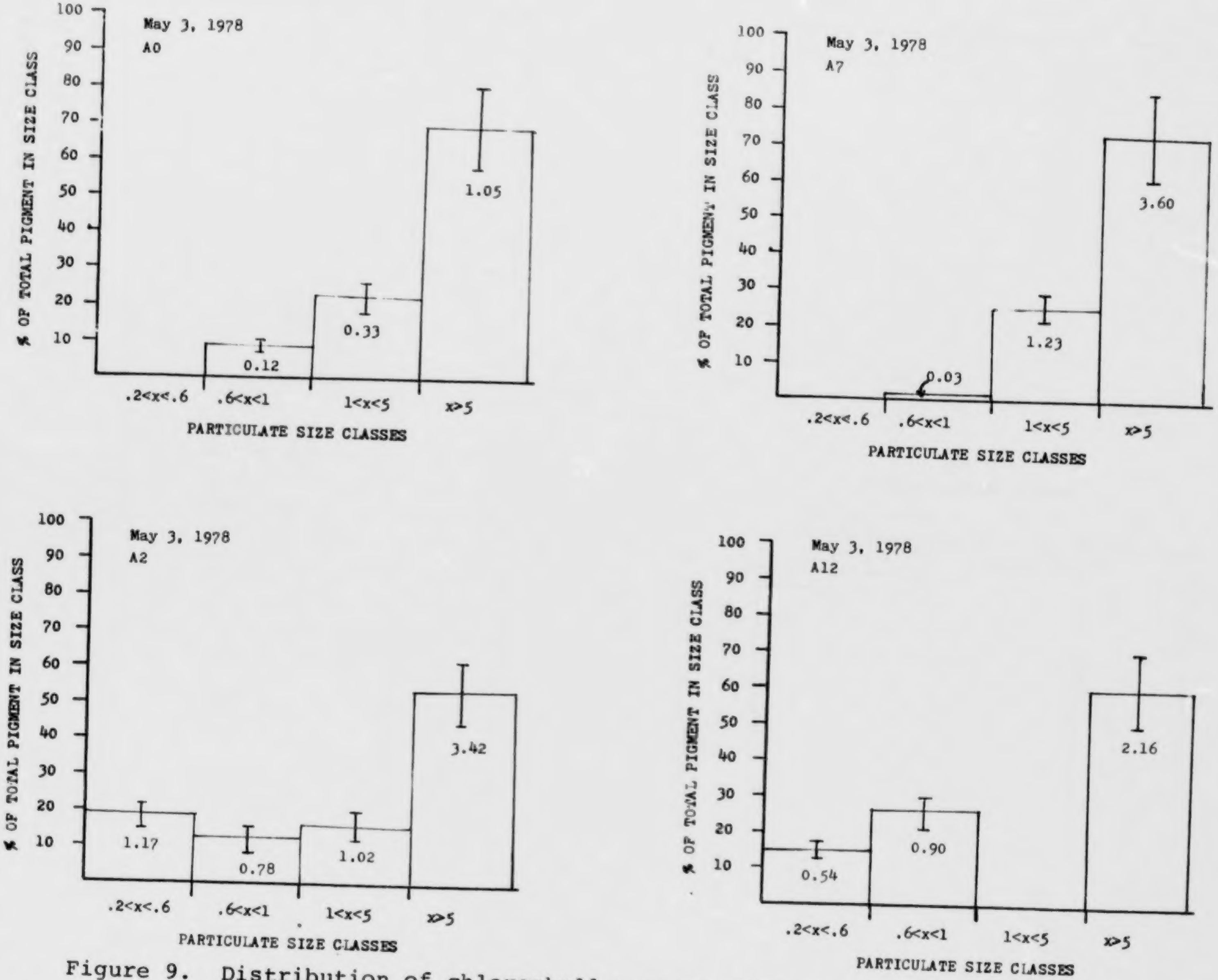

Figure 9. Distribution of chlorophyll *a* among size classes for May 3, 1978 sample.

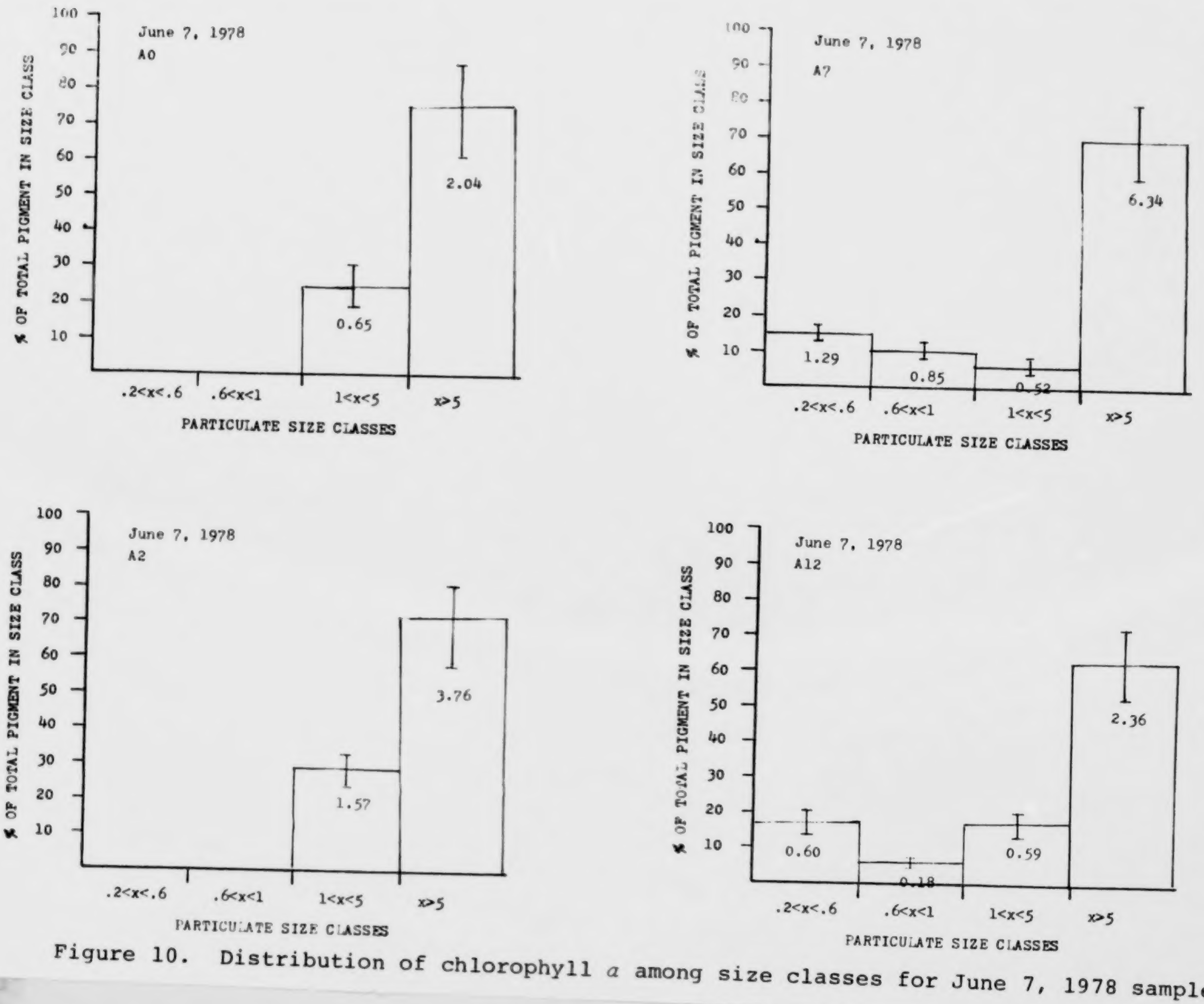

Figure 10. Distribution of chlorophyll *a* among size classes for June 7, 1978 sample.

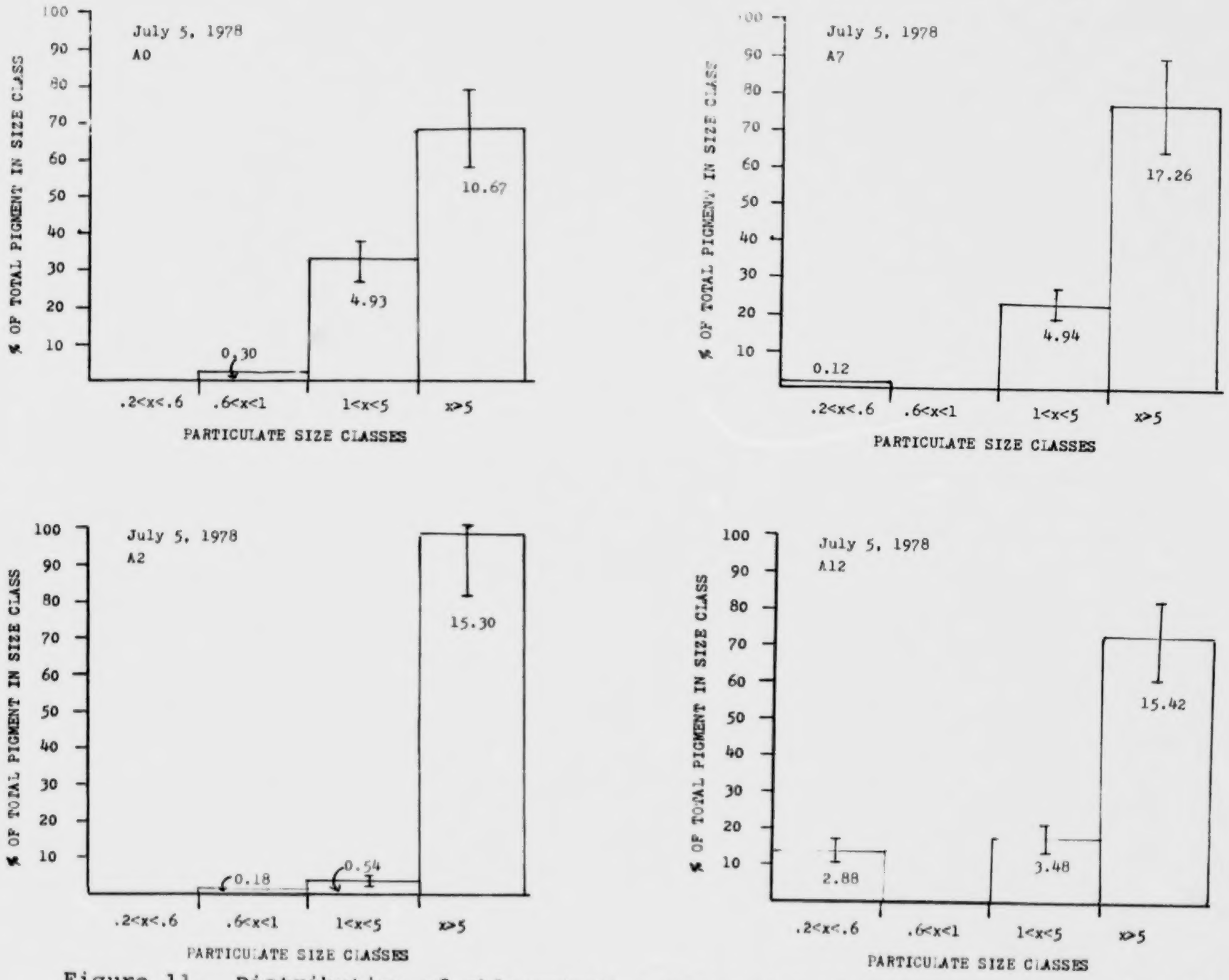

Figure 11. Distribution of chlorophyll *a* among size classes for July 5, 1978 sample.

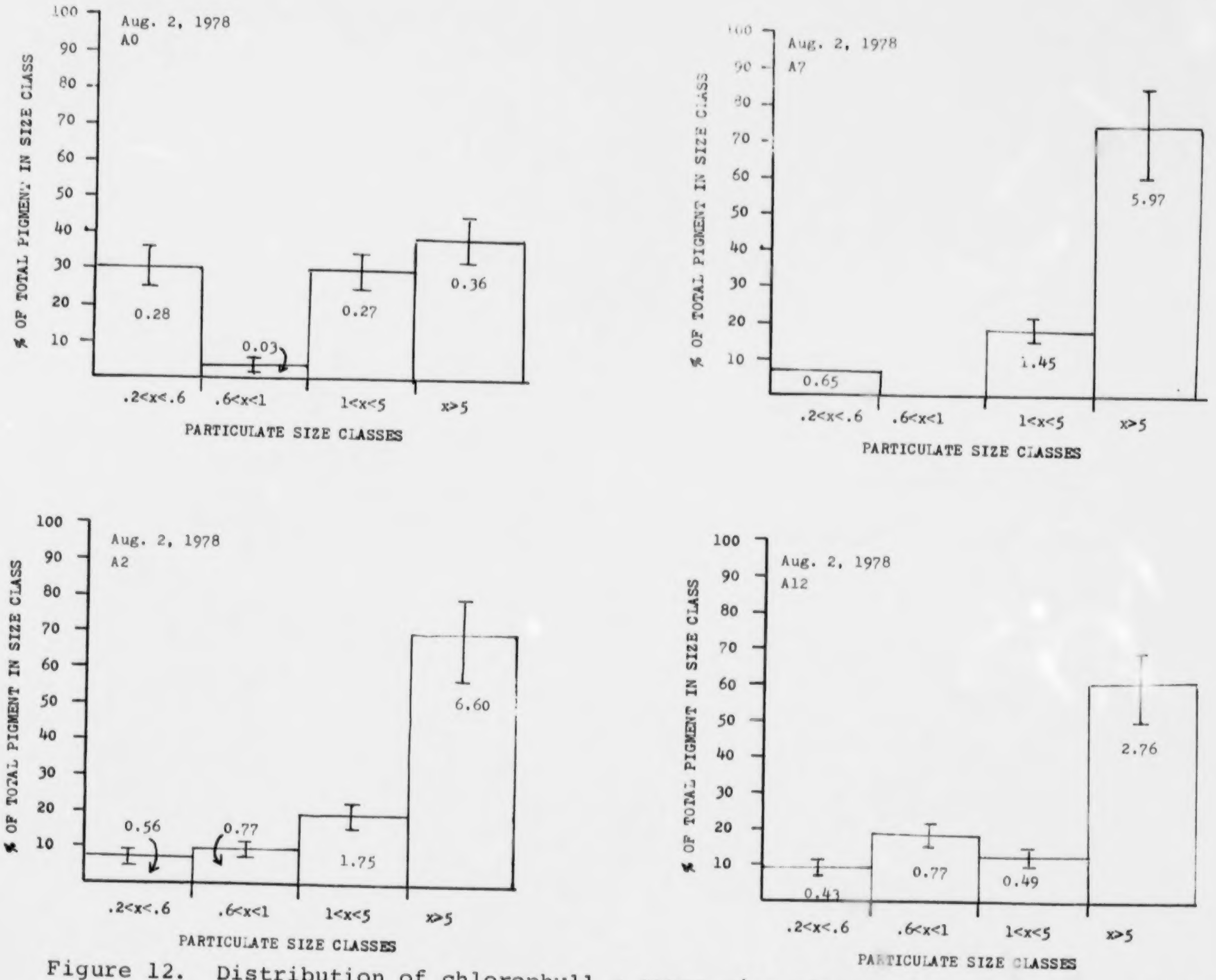

Figure 12. Distribution of chlorophyll *a* among size classes for August 2, 1978 sample.

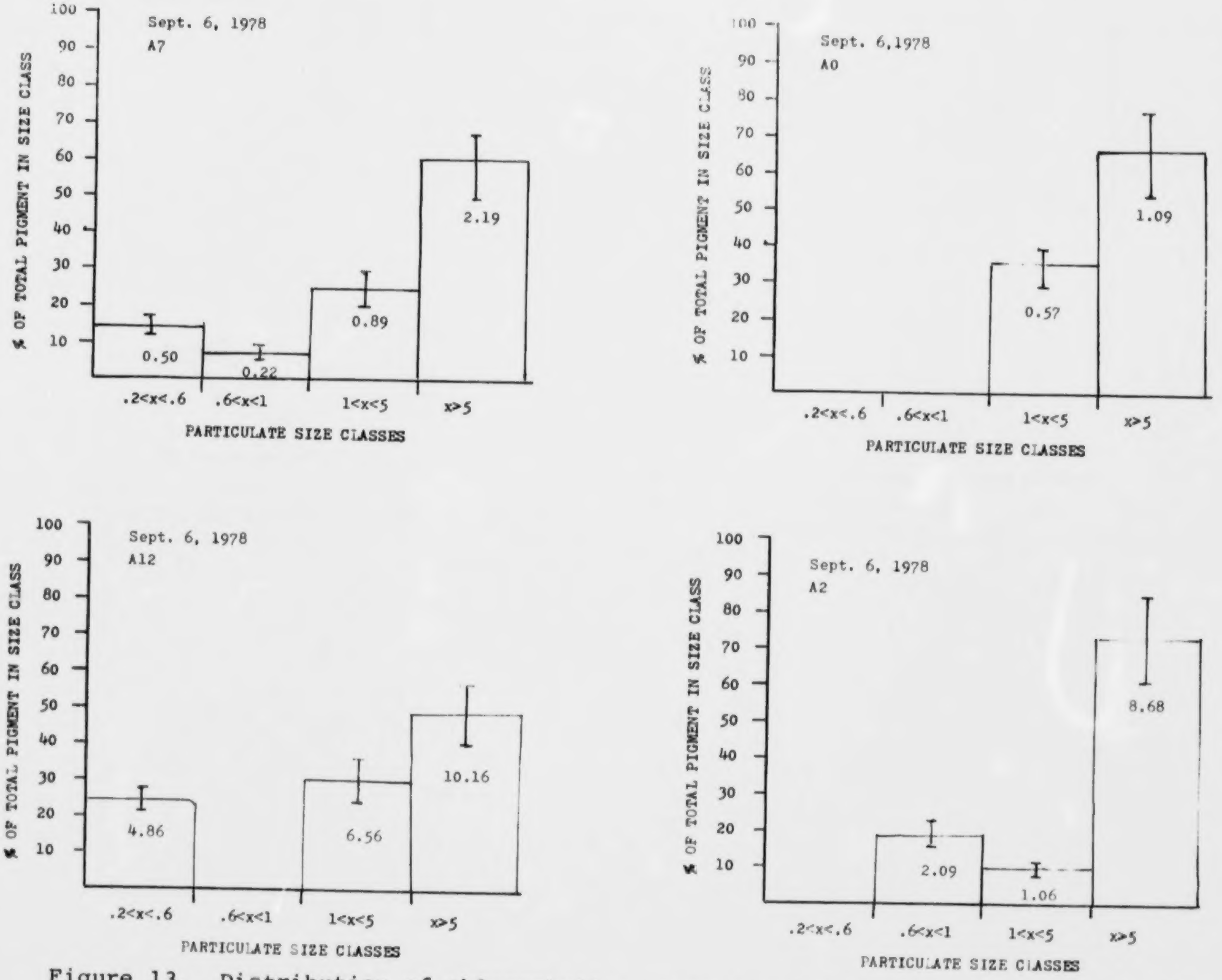

Figure 13. Distribution of chlorophyll *a* among size classes for September 6, 1978 sample.

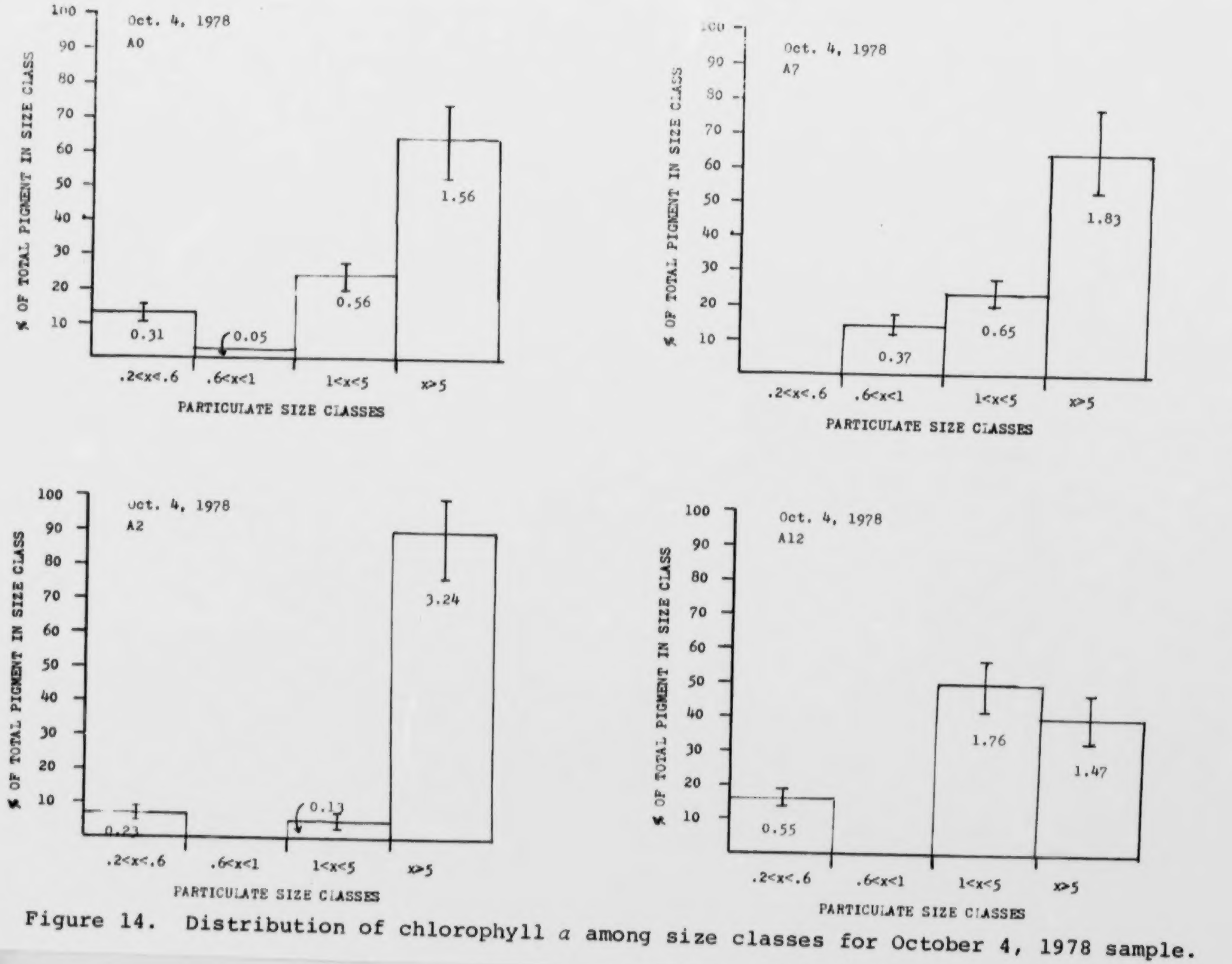

Figure 14. Distribution of chlorophyll *a* among size classes for October 4, 1978 sample.

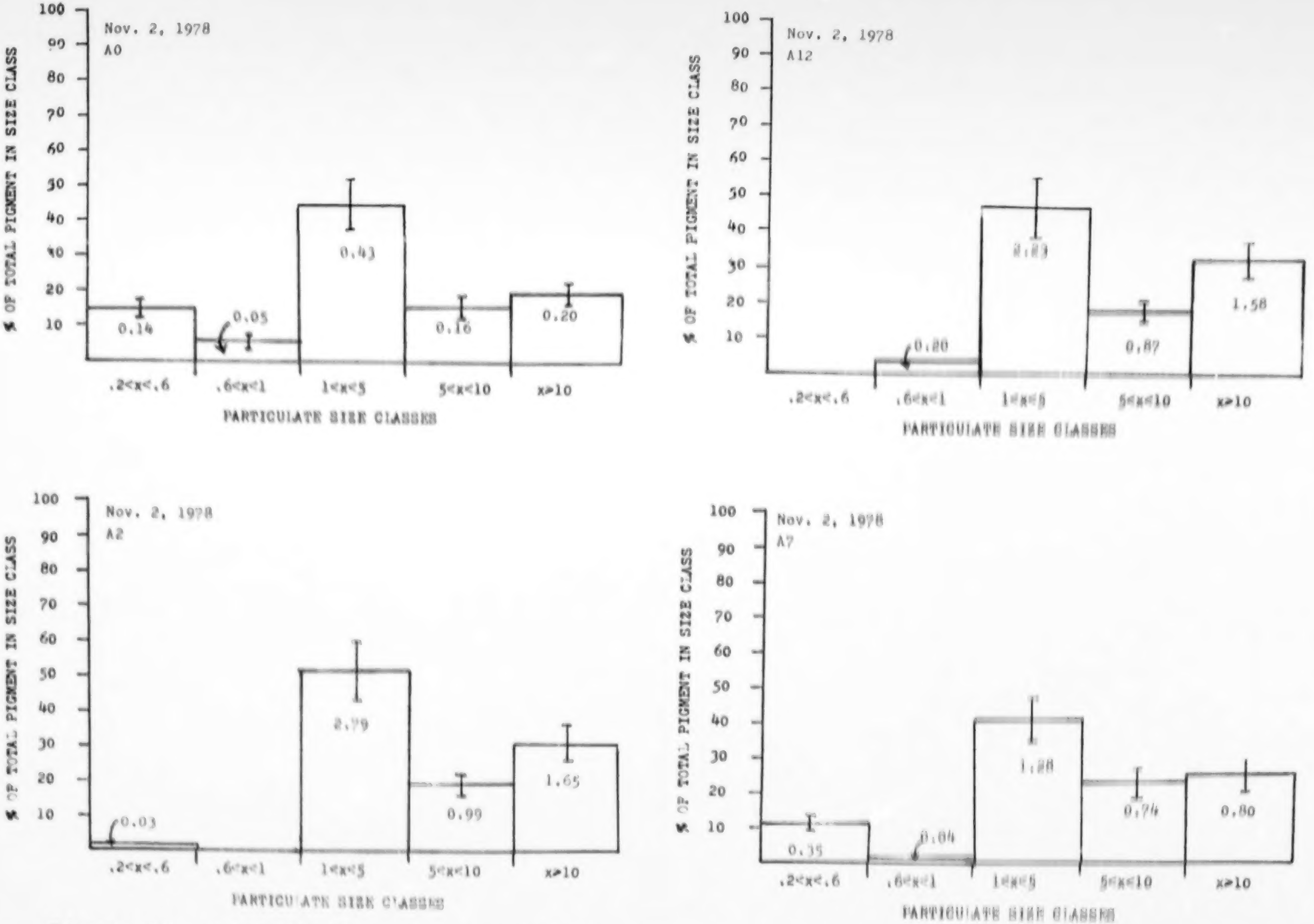

Figure 15. Distribution of chlorophyll *a* among size classes for November 2, 1978 sample.

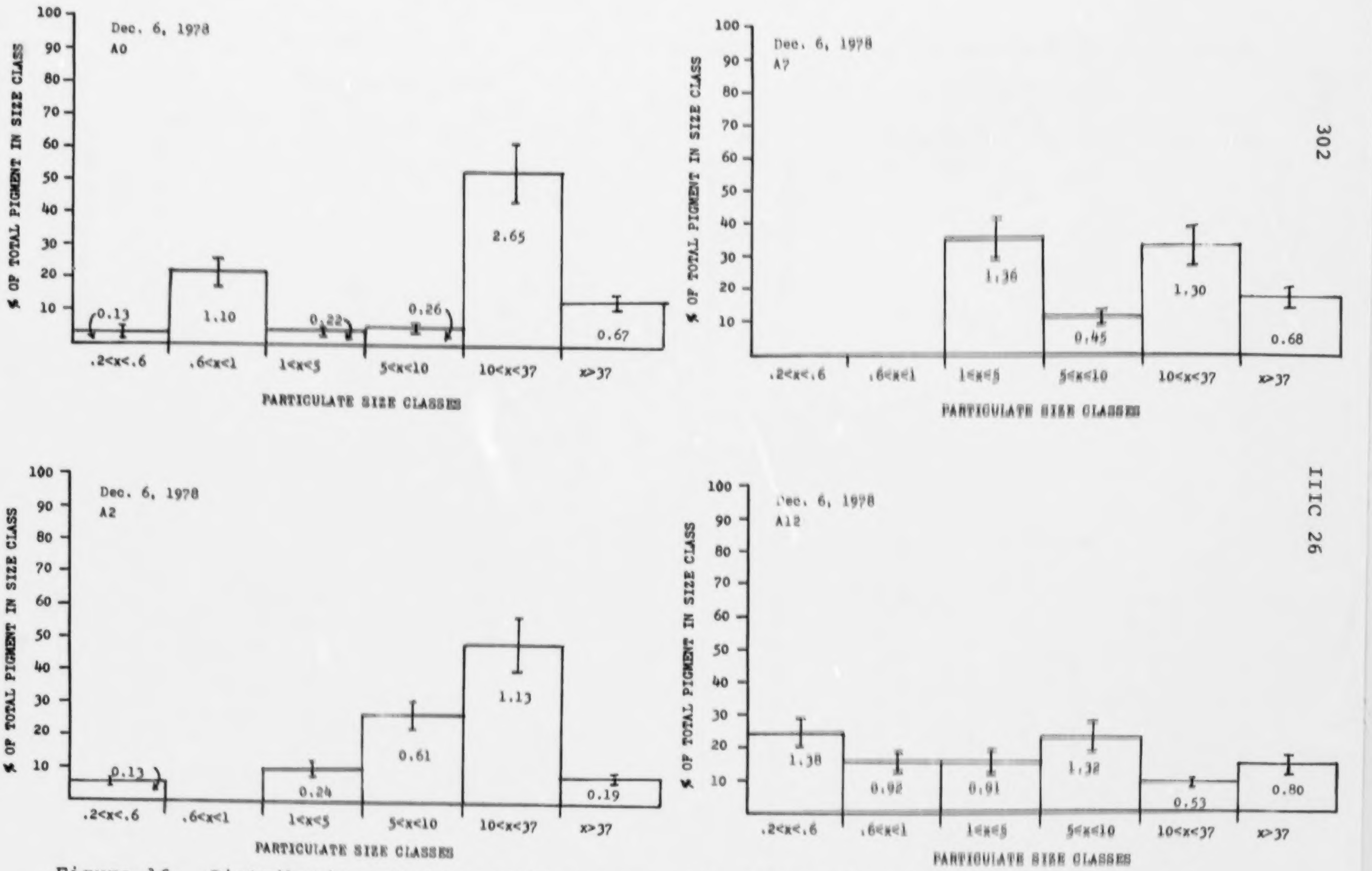

Figure 16. Distribution of chlorophyll *a* among size classes for December 6, 1978 sample.

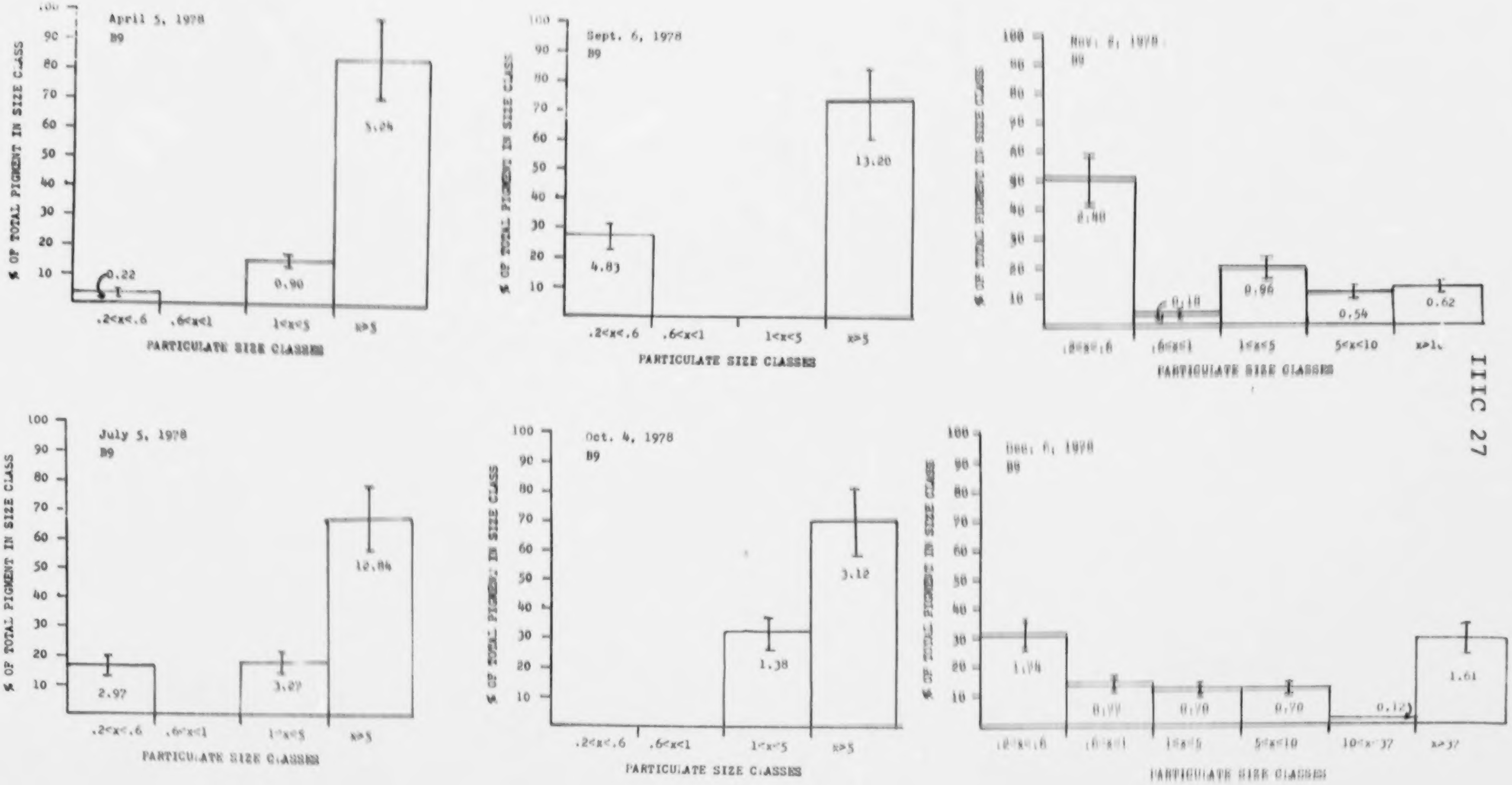

Figure 17. Distribution of chlorophyll *a* among size classes for April 5, 1978, July 5, 1978, September 6, 1978, October 4, 1978, November 2, 1978, and December 6, 1978 samples.

THE UPTAKE, SIZE FRACTIONATION, AND TURNOVER TIME OF ORTHOPHOSPHATE BY BACTERIOPLANKTON AND PHYTOPLANKTON IN THE LOS ANGELES HARBOR AND COASTAL WATERS

INTRODUCTION

Orthophosphate is one of several inorganic nutrients studied in characterizing the microbial activity in the outer Los Angeles Harbor. This nutrient is universally required by organisms and may be assimilated directly as PO_4^{-2} only by bacterioplankton and phytoplankton. Oceanic concentrations of phosphate are often at the lower limits of detection (0.03 to 5µmole·liter^{-1}) while turnover times, especially during phytoplankton blooms, are very short, usually minutes (Campbell, 1977).

The purposes of this investigation are fourfold:

1. To compare rates of uptake of orthophosphate, *in situ* phosphate concentrations, and turnover times (T_t) for phosphate between a station (A2) located inside the eutrophic Los Angeles Harbor and one (A0) outside the harbor breakwater, and among several depths at station A2.
2. To determine which size fractions of microplankton are responsible for the assimilation of orthophosphate.
3. To describe seasonal changes in turnover times for phosphate, especially in correlation with standing stocks of bacterioplankton and phytoplankton, and with the *in situ* phosphate concentration.
4. To evaluate the role of bacterioplankton in nutrient cycling in the food web of the outer harbor.

METHODS

In July, August and September 1978, samples of sea water were collected with sterile Niskin samplers from 1 m below the surface at four stations inside the harbor (A2, A7, A12, B9) and one station (A0) outside the harbor breakwater (see Figure 11) and filtered through a 203 µm Nitex net to remove larger plankton. Aliquots of 50 or 100 ml of each sample were filtered through a 0.2 µm pore-sized filter (Nuclepore) and stored frozen before dissolved reactive phosphate determination by the spectrophotometric method of Strickland and Parsons (1972).

All filtrations employed discrete pore-sized membrane filters (Nuclepore) which are hereafter designated as x µm filters where x = 0.2, 0.6, 1.0 or 5.0 µm. For the studies

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on uptake kinetics a 300 ml sample was incubated with stirring at 18 C and 3000 lux with approximately 1.3 µCi of either carrier-free $H_3{}^{32}PO_4$ or $H_3{}^{33}PO_4$. The addition of carrier-free label does not significantly alter the ambient phosphate concentration. At various intervals for up to 6 hours, 10 ml subsamples were filtered in duplicate through 1.0 µm and 0.2 µm filters at -10 cm Hg pressure, rinsed twice with 5 ml prefiltered 0.2 µm OC sea water (SW) and dried. The dried filters were placed in 10 ml of a toluene-based scintillation cocktail for counting in an LS-100 Beckman counting system. A 1 ml aliquot of the unfiltered sample was counted directly in Aquasol to yield total disintegrations per minute (dpm) of the radioisotope per volume of sample. Counts per minute (cpm) were converted to dpm by means of a quench curve.

Uptake values were corrected for nonbiological adsorption of the label by subtracting either an acid-killed or zero-hour (t_o) blank for each time point. Acid-killed controls were prepared by addition of 0.2 ml of 7% PCA to 100 ml of sample immediately before addition of the label; the final pH was 2. T_o controls were prepared by filtration of duplicate 10 ml subsamples immediately after addition of label to a live sample.

For the size fractionation studies, 200 ml seawater samples were incubated for 24 h under the conditions described above. At the end of this period, duplicate 10 ml subsamples were filtered onto 5.0, 1.0, 0.6 and 0.2 µm filters, which were rinsed, dried and counted as above. These filtrations were nonsequential. Either acid-killed or t_o controls were prepared for each sample.

Specific activity of the radio label was calculated from the dissolved reactive phosphate concentration and the total dpm ml^{-1} of unfiltered sample. The particulate uptake was calculated by conversion of dpm ml^{-1} to nmole $PO_4{}^{-2} \cdot liter^{-1}$, using the specific activity in nmole $PO_4{}^{-2} \cdot dpm^{-1}$. Uptake was plotted against incubation time to obtain a line, the slope of which was determined by linear regression analysis and expresses the particulate uptake rate, in nmole $PO_4{}^{-2} \cdot liter^{-1} \cdot h^{-1}$. Turnover times ($T_t$), defined by the equation $T_t = s/v$, where s = natural phosphate concentration in µmole $PO_4{}^{-2} \cdot liter^{-1}$ and v = particulate uptake rate, were calculated both from the kinetic experiments and from the single point incubations where uptake was size-fractionated. The percent uptake passing each filter size was computed, based on 200% retention by the 0.2 µm filter.

Specific uptake rates, reported as nmole $PO_4{}^{-2} \cdot mgC^{-1} \cdot h^{-1}$ are based on the assumption that uptake by the size fraction >0.2 µm, <1.0 µm is due to bacteria, while uptake by the size class >1.0 µm is primarily due to phytoplankton. This assumption is based on our own observations and on the data of Faust and Correll (1976) and Harrison *et al.* (1977), which showed that at least 80% of phosphate uptake by cells >1.0 μm is algal, while at least 90% of the uptake passing a 1 μm filter and retained by an 0.2 μm filter is bacterial. Determination of bacterial and phytoplankton standing stocks was by the acridine orange direct counting technique (AODC) according to Daley and Hobbie (1978) and chlorophyll *a* biomass estimates by the fluorometric technique of Strickland and Parsons (1972). These values were converted to mgC as explained elsewhere in this report.

RESULTS

The kinetics of phosphate uptake were studied for three size classes of microorganisms at stations A2 and A0 (Figures 1 and 2). Total uptake and uptake by the >1.0 μm size class were measured directly; uptake by the bacterioplankton was determined by subtraction. In all cases uptake was linear over 6 hours, with a correlation coefficient >0.93 at a significance level of 0.05 when analyzed by least squares linear regression.

At station A2, where the reactive phosphate concentration was measured at 0.59 μmole $PO_4^{-2}\cdot liter^{-1}$, turnover time of phosphate was 41.2h and uptake rate (v) was 14.4 nmole $PO_4^{-2}\cdot liter^{-1}\cdot h^{-1}$ for the total population. For the >1.0 μm size fraction, T_t was 74.1 hours, and v was 8.0 nmole $PO_4^{-2}\cdot liter^{-1}\cdot h^{-1}$, while T_t and v by the bacterioplankton were 95.6h and 6.8 nmole $PO_4^{-2}\cdot liter^{-1}\cdot h^{-1}$ respectively.

At station A0, where the phosphate concentration was 0.78 μmole $PO_4^{-2}\cdot liter^{-1}$, v for the total population was slower, 11.18 nmole $PO_4^{-2}\cdot liter^{-1}\cdot h^{-1}$ and T_t was 1.5 times longer, at 69.6 hours. The bacterioplankton population took phosphate up at a rate similar to that at A2, with a v = 7.1 nmole $PO_4^{-2}\cdot liter^{-1}\cdot h^{-1}$ and T_t of 109.8h. Bacterioplankton uptake at A0 was 50% of the total, while at A2 it was 30% of the total. The bacterioplankton standing stock at A2 was 5-fold that at A0 for this sampling date.

Figures 3 and 4 present the data for the vertical profile study of phosphate uptake at station A2. Only total uptake was measured. Although the *in situ* phosphate concentration differed by less than 0.35 μmole $PO_4^{-2}\cdot liter^{-1}$ in the upper 10 meters, T_t increased greatly with depth below 3 meters. The sample collected at 3m showed the highest uptake rate, at 8.74 nmole $PO_4^{-1}\cdot liter^{-1}\cdot h^{-1}$ with a T_t of 139 h (5.8 days). The sample collected from 9 meters showed no significant uptake after 3 h. Figure 4 indicates that uptake rate closely parallels the natural phosphate concentration with depth.

Figure 5 presents the data for an experiment, in which the total uptake at station A0 was compared to that at station

A2, over a 5 h incubation period. Only total uptake was measured, which was linear for both stations with a correlation >0.95 at the 0.05 significance level. At station A2, the uptake rate for this experiment in September was more than triple that of the first two experiments done in July and August, with a September value of 49.1 nmole $PO_4^{-2}\cdot liter^{-1} \cdot h^{-1}$. The T_t was 25.5 h and the phosphate concentration was similar to that measured in August: 1.25 µmole $PO_4^{-2}\cdot liter^{-1}$ and a 1.12 µmole $PO_4^{-2}\cdot liter^{-1}$, respectively. At A0 the uptake kinetics for September approximate those in July, the T_t being 75.1 h and the uptake velocity = 10.4 nmole $PO_4^{-2}\cdot liter^{-1}\cdot h^{-1}$. The phosphate concentration was the same in both months, 0.78 µmole $PO_4^{-2}\cdot liter^{-1}$.

Table 1 summarizes all of the kinetic data. In Figures 6-10 and Tables 2-4, the results of the 24 h fractionation studies are given.

At all stations but A7, the uptake rate at least doubled in September as compared with July. At A7 the uptake rate actually decreased in September. This sample may have become anoxic during the long incubation, as it smelled strongly of H_2S when the 24 h filtrations were performed. Aside from this anomalous rate decrease at station A7, several patterns emerged from the data: 1) In both months, A0 had the lowest rates of uptake by all size fractions; at this station the microorganisms <5 µm in smallest diameter were responsible for at least 80% of the total uptake, while those <0.6 µm achieved at least 55% of the total uptake; 2) at stations A12 and B9 similar rates of uptake were obtained for a given sampling period. At these stations about 70% of the total uptake passed a 5 µm filter, 55% passed a 1 µm filter, and 50% passed a 0.6 µm filter; 3) although the uptake rate at A2 is more than doubled from July to August, the uptake distribution was about the same for both months, with about 80% passing a 5 µm filter, 70% passing a 1 µm filter, and 55% passing a 0.6 µm filter; 4) a dramatic increase in the percent uptake retained by the 0.6 µm and larger pore-sized filters was seen in the September samples of stations A2 and A7. At station A2, 56% of the total uptake passed a 5 µm filter and 25% passed a 0.6 µm filter in September, whereas these values were 76% and 54%, respectively, in July. At A7, 15% of the total uptake passed a 5 µm filter and 7% passed a 0.6 µm filter in September, as compared with 80% and 38%, respectively, in July.

Table 5 (D. Krempin, personal communication) shows the bacterioplankton standing stocks at these five stations for the two months sampled. At every station the population increased at least twofold in September. A dinoflagellate bloom of *Gymnodinium splendens* also occurred in the Los Angeles Harbor in September. Phytoplankton standing stocks, estimated from µg chlorophyll a $liter^{-1}$ are found in Table 6 (J. SooHoo, personal communication). In Table 7, orthophosphate uptake per μg bacterioplankton and phytoplankton carbon has been calculated. Phosphate uptake by bacterioplankton per unit biomass proceeds at a rate 17 to 1000 times greater than that by phytoplankton. However, because the phytoplankton standing stock is 60 to 400 times bacterioplankton biomass, the rates at which these two size classes take up phosphate are of approximately the same magnitude on a volume basis.

In Figures 6 through 10 and Tables 2 through 4, the results of the 24 h fractionation studies are presented. At all stations but A7 uptake more than doubled in September compared with July. In July, bacterioplankton are responsible for at least 50% of total uptake at all stations, while in September, uptake by the >1.0 μm size fraction was over 60% of the total at stations A2 and A7. Turnover times of phosphate by the total population ranged from 47 h at station B9 in September to 159 h at station A0 in July.

DISCUSSION

Although phosphate is a limiting nutrient in many oceanic environments, this is probably not the case in the eutrophic waters of the Los Angeles Harbor. The range of concentrations for the five stations discussed in this report was 0.5 to 3.0 μmole $PO_4^{-2}\cdot\text{liter}^{-1}$ over the three months in which phosphate was measured. This is similar to concentrations found in the coastal region around San Diego: 0.64 to 2.34 μmole $PO_4^{-2}\cdot\text{liter}^{-1}$ (Solorzano and Strickland, 1968) and in the Rhode River subestuary of Chesapeake Bay: 4.0 μmole $PO_4^{-2}\cdot\text{liter}^{-1}$ (Frieble *et al.*, 1978). It is high compared to that measured off La Jolla, California: 0.2 to 0.7 μmole $PO_4^{-2}\cdot\text{liter}^{-1}$ and in the oligotrophic waters of the East-Central Pacific; 0.05-0.70 μmole $PO_4^{-2}\cdot\text{liter}^{-1}$ (Solorzano and Strickland, 1968).

Two important points emerge from the kinetic data (Table 2):

1. At station A2, a doubling in the bacterial population (Table 5) from July to September, 1978 corresponded with a threefold increase in uptake rate. Phosphate concentration also doubled over this interval, whereas phytoplankton biomass decreased slightly (Tables 5, 6). From July to August the bacterial population at station A2 dropped 30% and uptake rate was correspondingly halved; *in situ* phosphate concentration almost doubled. Phytoplankton biomass also dropped about 30% in August. These changes were correlated with TITP in August, following chlorination during a breakdown of the treatment system from May through July. These observations are in agreement with the finding of Faust and Correll (1976), that the phosphate assimilation ability of bacteria and algae in the Chesapeake Bay had high correlations only with biomass,

and were not influenced by the in situ phosphate concentration.

The data for station A0 are more difficult to interpret. Neither phosphate concentration nor uptake rate changed significantly between July and September despite a tripling of the bacterial population. Phytoplankton decreased more than sevenfold, but the data presented in Figure 1 indicates that uptake by this size class is less than 50% of the total. While the specific uptake rate (nmole$\cdot 10^9$ cell$^{-1}\cdot$h^{-1}) at A2 varies only about twofold, from 6.4 in July to 12.0 in September, at A0 it ranges fourfold, from 7.0 in September to 28.7 in July. In January (unpublished data) this rate drops to 2.2 at A0. This indicates that the bacterioplankton at A2 are metabolically more active and less variable than those outside the breakwater.

2. The results of the vertical profile (Figure 4) show a subsurface maximum for bacterial and phytoplankton density as well as for the in situ phosphate concentration and the uptake rate by the microplankton at a 3 meter depth, followed by a uniform decrease in all these parameters to 0 m depth. This differs from the depth profiles of Harrison et al. (1977) off British Columbia, which showed maxima for both phosphate assimilation and in situ concentrations below 10 m depth.

A phytoplankton bloom occurred throughout the harbor in July (Table 6) but the standing stock dropped in August. In September, phytoplankton peaks equal in magnitude to the July bloom occurred at stations A12 and B9, while bacterial populations increased two- and 1.3-fold, respectively. Relative uptake into different size classes did not change significantly (Figures 8 and 9). Smaller phytoplankton blooms were measured at stations A2 and A0 in September, when bacterial populations increased 1.8- and 4-fold, respectively, over the July standing stocks. Table 7 shows that the uptake of phosphate per µg phytoplankton carbon increased at every station from July to September, but the increase was greatest at station A0 (18-fold) and A2 (6-fold). The uptake of phosphate per µg bacterial carbon remained about the same for all stations except A7, where it decreased 28-fold between July and September. The uptake data for station A7 may be an artifact of that sample having become anoxic, as discussed earlier. The trends at the other stations, however, suggest a hypothesis: early in a phytoplankton bloom (such as at stations A0 and A2 in September) the phytoplankton population may "gear up" for rapid growth and divisions by storing up nutrients, such as phosphate, beyond their immediate needs. The physiological status characterizing these organisms at that time would enable them to compete better with bacterioplankton for dissolved phosphate. Later in the bloom (as in the July peak), the phytoplankton probably play a less important role in phosphate uptake, relative to the heterotrophic population. The bacterioplankton are increasing in response to the greater availability of dissolved organic carbon in the water column, presumably resulting from phytoplankton excretion lysis and grazing effects. Since the uptake rate per unit of bacterioplankton biomass exceeds that per unit of phytoplankton biomass by 17- to 1000-fold, the greater density of bacterioplankton enables these heterotrophs to outcompete the phytoplankters for nutrients.

This hypothesis is not consistent with the observation of Faust and Correll (1976) that higher phosphate assimilation by algae is due to higher numbers of algae rather than higher phosphate-assimilation ability per cell, but is supported by laboratory culture experiments of Rhee (1973) and Lean and Nalewajko (1976), which demonstrated the ability of algae to store excess phosphorus before undergoing several cell divisions.

Turnover times reported here (Tables 1, 2, 3 and 4) are high. Campbell (1977) states that turnover times are measured in minutes at the sea surface during summer months. However, the shortest turnover time recorded in the present study was 25 h at station A2 in July. This is undoubtedly the result of a high phosphate input into these coastal waters and/or rapid recycling of the resident PO_4^{-2} in the water column, since the phosphate concentration remained high even during the phytoplankton blooms. The overall predominance of bacterioplankton in phosphate uptake (Table 7) supports the findings of Fuhs _et al_. (1972) and Rhee (1972) that phytoplankters are out-competed by bacteria when the phosphate concentration is greater than 0.1 μmole $PO_4^{-2} \cdot liter^{-1}$. However, the long turnover times recorded here suggest that PO_4^{-2} is not a limiting nutrient to phytoplankton in the Los Angeles Harbor. This conclusion is supported by evidence presented elsewhere in this report, where laboratory cultures of phytoplankters were grown in harbor sea water supplemented with various concentrations of TITP effluent.

CONCLUSIONS

The following points summarize the experimental results concerning the uptake of orthophosphate by the bacterioplankton and phytoplankton in the Los Angeles Harbor and Coastal waters.

1. _In situ_ concentrations of PO_4^{-2} at four stations (A2, A7, A12, B9) inside the harbor and one (A0) outside the harbor breakwater are found within the range 0.5 to 3.0

μmole·liter^{-1} over the period from July 1978 to February 1979. These values are consistent with measurements reported in the literature for highly eutrophic waters.

2. Uptake of orthophosphate (as $H_3{}^{32}PO_4$ and $H_3{}^{33}PO_4$) is linear over seven hours by the >0.2 μm microplankton in seawater samples from a 1 meter depth at stations A2 and A0. At A0, uptake rate per volume water is remarkably constant, ranging from 10.4 to 11.2 nmole $PO_4{}^{-2}$·liter^{-1}·h^{-1} between July and January. At A2, the uptake rate varies 7-fold, from 49.1 to 6.7 nmole $PO_4{}^{-2}$·liter^{-1}·h^{-1} in September and January respectively. By contrast, the specific uptake rate (nmole $PO_4{}^{-2}$·10^9 cell^{-1}·h^{-1}) varies 13-fold at A0, from 2.2 in January to 28.7 in July, whereas at A2 the specific uptake rate varies only 2.5-fold. This indicates that the bacterioplankton at A2 are metabolically more active and less variable than those outside the breakwater.

3. A vertical profile at station A2 in August revealed subsurface maxima both for $PO_4{}^{-2}$ concentration and phosphate uptake rate by the microplankton at 3 meters, the depth at which the greatest bacterioplankton and phytoplankton population densities also occurred.

4. The shortest turnover time measured was 25 hours at A2 in September 1978. The mean turnover time at A0 was 64 hours. These data suggest that $PO_4{}^{-2}$ is not a limiting nutrient in these highly eutrophic waters, a conclusion also reached with laboratory cultures grown in harbor sea water supplemented with various concentrations of TITP effluent, as reported elsewhere in this volume.

5. Fractionation of the uptake data into four size classes (>5.0, >1.0, >0.6, >0.2 μm) showed that, while generally 60 to 80% of the label passed a 1.0 μm filter and can be considered with bacterioplankton, up to 60% of the label was retained by a 1.0 μm filter in September, and 50% in July. This increase in uptake by the larger size class is strongly correlated with the occurrence of phytoplankton blooms in these months. Overall, the uptake rate per unit bacterioplankton carbon was 17 to 1000 times the rate per phytoplankton carbon. The difference in uptake rates was much greater in July, when phytoplankton biomass was 60 to 400 times bacterioplankton biomass, than in September, when the biomass difference was 8- to 55-fold. These data indicate that bacterioplankton are the predominant organisms involved in uptake of dissolved orthophosphate in the Los Angeles Harbor.

LITERATURE CITED: See Section VI.

Table 1. A summary of kinetic data for orthophosphate uptake at stations A_2 and A_0, Summer 1978

Sample date	Sample depth meters	Station	Size fraction involved	s µmole $PO_4^{-2} \cdot liter^{-1}$	v nmole $PO_4^{-2} \cdot liter^{-1} \cdot h^{-1}$	T_t hours
7-5-78	1 m	A_0	>0.2µm	0.78	11.18	69.6
			>0.2µm,<1.0µm		7.10	109.8
			>1.0µm		4.13	190.8
7-5-78	1 m	A_2	>0.2µm	0.592	14.37	41.2
			>0.2µm,<1.0µm		6.17	95.6
			>1.0µm		7.99	74.1
8-16-78	1 m	A_2	>0.2µm	1.12	7.91	141.6
	3 m		"	1.22	8.74	139.6
	6 m		"	0.97	4.26	227.7
	9 m		"	0.88	0.35	2521.5
	10 m		"	0.96	2.87	334.5
9-6-78	1 m	A_0	>0.2µm	0.78	10.39	75.1
	1 m	A_2	>0.2µm	1.25	49.12	25.5

Table 2. A summary of the 24 hour size fractionation data for orthophosphate uptake, 7-5-78. Label assayed $H_3{}^{33}PO_4$

Stations:	A_0	A_2	A_7	A_{12}	B_9
Size Fraction (μm)	dpm retained ± S.D.	dpm retained ± S.D.	dpm retained ± S.D.	dpm retained ± S.D.	dpm retained ± S.D.
5	2515 ± 89.0	10321 ± 835	8431 ± 26.2	11292 ± 268	16380 ± 326
1	7179 ± 34.5	11592 ± 439	17060 ± 72.7	19528 ± 178	22059 ± 993
0.6	4015 ± 164	19843 ± 665	24397 ± 284	22114 ± 181	25123 ± 484
0.2	13197 ± 422	42986 ± 1138	39672 ± 1221	41322 ± 1965	47210 ± 3050
	nmoles retained $\cdot L^{-1} \cdot h^{-1}$	nmoles retained $\cdot L^{-1} \cdot h^{-1}$	nmoles retained $\cdot L^{-1} \cdot h^{-1}$	nmoles retained $\cdot L^{-1} \cdot h^{-1}$	nmoles retained $\cdot L^{-1} \cdot h^{-1}$
5	0.929 ± 0.062	2.25 ± 0.18	11.4 ± 0.03	2.68 ± 0.14	2.45 ± 0.02
1	1.285 ± 0.013	2.53 ± 0.09	23.2 ± 0.09	4.51 ± 0.04	3.40 ± 0.09
0.6	1.572 ± 0.065	4.35 ± 0.14	33.2 ± 0.38	5.11 ± 0.04	3.88 ± 0.07
0.2	4.876 ± 0.156	9.44 ± 0.25	54.1 ± 1.66	9.55 ± 0.45	7.68 ± 0.08
	% passing	% passing	% passing	% passing	% passing
5	80.9	76.1	78.7	71.8	68.0
1	73.6	73.1	57.0	52.7	55.6
0.6	67.7	53.8	38.5	46.5	49.4
0.2	0	0	0	0	0
	T_t hours	T_t hours	T_t hours	T_t hours	T_t hours
5	837	262	259	178	162
1	605	233	128	106	117
0.6	494	135	89	94	103
0.2	159	62	55	50	52
μmole $PO_4^{-2} \cdot liter^{-1}$	0.78	0.59	2.98	0.48	0.40

Table 3. A summary of the 24 hour size fractionation data of orthophosphate uptake for 5 depths at station A2, 8-16-78. Label assayed $H_3{}^{32}PO_4$

Depth	1 m	3 m	6 m	9 m	10 m
Size Fraction (μm)	dpm retained ± S.D.	dpm retained ± S.D.	dpm retained ± S.D.	dpm retained ± S.D.	dpm retained ± S.D.
5	3652 ± 123	4383 ± 84.7	4024 ± 213	3320 ± 288	5462 ± 431
1	9686 ± 293	12640 ± 24.1	8323 ± 57.7	5923 ± 10	12212 ± 46.1
0.6	12245 ± 436	16161 ± 157	11093 ± 354	6683 ± 127	17628 ± 107
0.2	31073 ± 443	39995 ± 493	22161 ± 4285	11871 ± 3321	35287 ± 438
	nmoles retained $\cdot L^{-1} \cdot h^{-1}$	nmoles retained $\cdot L^{-1} \cdot h^{-1}$	nmoles retained $\cdot L^{-1} \cdot h^{-1}$	nmoles retained $\cdot L^{-1} \cdot h^{-1}$	nmoles retained $\cdot L^{-1} \cdot h^{-1}$
5	2.8 ± 0.09	3.36 ± 0.06	2.63 ± 0.13	2.02 ± 0.17	3.66 ± 0.29
1	7.42 ± 0.22	9.69 ± 0.01	5.44 ± 0.03	3.60 ± 0.00	8.19 ± 0.03
0.6	9.38 ± 0.330	12.39 ± 0.06	7.25 ± 0.23	4.09 ± 0.10	11.82 ± 0.07
0.2	23.82 ± 0.34	30.660± 0.37	14.49 ± 2.80	7.22 ± 2.02	23.67 ± 0.29
	% passing	% passing	% passing	% passing	% passing
5	88.2	89.2	81.8	72.0	84.50
1	68.8	68.4	62.4	50.1	65.5
0.6	60.5	59.5	50.0	43.3	50.0
0.2	0	0	0	0	0
	T_t hours	T_t hours	T_t hours	T_t hours	T_t hours
5	400	363	368	435	261
1	150	125	178	244	117
0.6	119	98	133	215	81
0.2	47	39	64	121	40
μmole $PO_4^{-2} \cdot liter^{-1}$	1.12	1.22	0.97	0.88	0.96

Table 4. A summary of the 24 hour size fractionation data for orthophosphate uptake, 9-6-78. Label assayed $H_3{}^{32}PO_4$

Stations:	A_0	A_2	A_7	A_{12}	B_9
Size Fraction (μm)	dpm retained ± S.D.	dpm retained ± S.D.	dpm retained ± S.D.	dpm retained ± S.D.	dpm retained ± S.D.
5	3576 ± 677	13342 ± 600	9841 ± 679	9425 ± 126	9309 ± 133
1	6749 ± 584	19033 ± 81.4	9681 ± 222	11918 ± 1211	14152 ± 401
0.6	13847 ± 218	23038 ± 450	10722 ± 162	15233 ± 2007	17935 ± 1088
0.2	31655 ± 292	30880 ± 344	11606 ± 753	24361 ± 1455	35395 ± 1977
	nmoles retained $\cdot L^{-1} \cdot h^{-1}$	nmoles retained $\cdot L^{-1} \cdot h^{-1}$	nmoles retained $\cdot L^{-1} \cdot h^{-1}$	nmoles retained $\cdot L^{-1} \cdot h^{-1}$	nmoles retained $\cdot L^{-1} \cdot h^{-1}$
5	1.59 ± 0.30	8.26 ± 0.37	8.24 ± 0.56	7.81 ± 0.10	4.61 ± 0.12
1	2.99 ± 0.26	11.67 ± 0.05	8.10 ± 0.18	9.88 ± 2.17	7.01 ± 0.13
0.6	6.15 ± 0.09	14.19 ± 0.28	8.98 ± 0.13	12.63 ± 1.66	8.89 ± 0.54
0.2	14.08 ± 0.13	19.06 ± 0.21	9.72 ± 0.63	20.20 ± 1.20	17.55 ± 0.98
	% passing	% passing	% passing	% passing	% passing
5	88.7	56.6	15.2	61.3	73.7
1	78.7	38.7	16.5	51.0	60.0
0.6	56.3	25.5	7.6	37.4	49.3
0.2					
	T_t hours	T_t hours	T_t hours	T_t hours	T_t hours
5	490	140	173	185	182
1	260	107	176	146	119
0.6	126	88	159	114	94
0.2	55	65	147	71	47
μmole $PO_4^{-2} \cdot liter^{-1}$	0.78	1.25	1.43	1.45	0.84

Table 5. Standing stocks and biomass estimates of bacterioplankton at 5 stations in the Los Angeles Harbor area, July - September 1978. Estimates are based on direct counts using epifluorescent microscopy.

Sample date	Station	Sample depth (meters)	Total bacterioplankton $(\cdot 10^5)\cdot ml^{-1}$	Bacterial biomass $\mu g\ C\cdot liter^{-1}$
7-5-78	A_0	1 m	3.9 ± 0.6	3.1 ± 0.5
	A_2	1 m	22.5 ± 2.7	17.6 ± 2.1
	A_7	1 m	29.1 ± 2.3	22.8 ± 1.8
	A_{12}	1 m	16.9 ± 0.9	13.2 ± 0.7
	B_9	1 m	27.6 ± 2.1	21.6 ± 1.6
8-16-78	A_2	1 m	11.4 ± 3.6	12.8 ± 2.8
		3 m	18.9 ± 3.6	14.8 ± 2.8
		6 m	15.7 ± 2.4	12.3 ± 1.9
		9 m	10.5 ± 3.1	8.2 ± 2.4
		10 m	9.2 ± 3.2	7.2 ± 2.5
9-6-78	A_0	1 m	14.8 ± 1.9	11.6 ± 1.5
	A_2	1 m	40.8 ± 4.0	31.9 ± 3.1
	A_7	1 m	43.3 ± 5.6	33.9 ± 4.4
	A_{12}	1 m	36.2 ± 6.2	28.3 ± 4.9
	B_9	1 m	35.4 ± 4.4	27.7 ± 3.4

Table 6. Standing stock estimates of phytoplankton biomass at 5 stations in the Los Angeles Harbor, July - September 1978. Estimates are based on chlorophyll *a* measurements according to the method of Strickland and Parsons, 1972.

Sample date	Station	μg chlorophyll *a*·liter^{-1}	mg phytoplankton C·liter^{-1}
7-5-78	A_0	15.5	1.2
	A_2	15.9	1.2
	A_7	42.2	1.3
	A_{12}		1.65
	B_9	22.0	1.5
8-2-78	A_0	0.1	0.1
	A_2	10.5	0.7
	A_7	8.0	0.7
	A_{12}		0.4
	B_9	4.8	0.3
9-6-78	A_0	1.0	0.15
	A_2	10.8	0.9
	A_7	4.1	0.3
	A_{12}		1.6
	B_9	22.0	1.35

Table 7. Relative uptake of orthophosphate by bacterioplankton and phytoplankton based on biomass estimates of the standing stocks, summer 1978.

Sample date	Station	Uptake rate of bacterioplankton nmole $PO_4^{-2} \cdot \mu g\ C^{-1} \cdot h^{-1}$	Uptake rate of phytoplankton nmole $PO_4^{-2} \cdot \mu g\ C^{-1} \cdot h^{-1}$
7-5-78	A_0	1.16	0.001
	A_2	0.392	0.002
	A_7	1.35	0.018
	A_{12}	0.379	0.003
	B_9	0.199	0.002
9-6-78	A_0	0.957	0.02
	A_2	0.232	0.013
	A_7	0.047	0.027
	A_{12}	0.364	0.006
	B_9	0.383	0.005

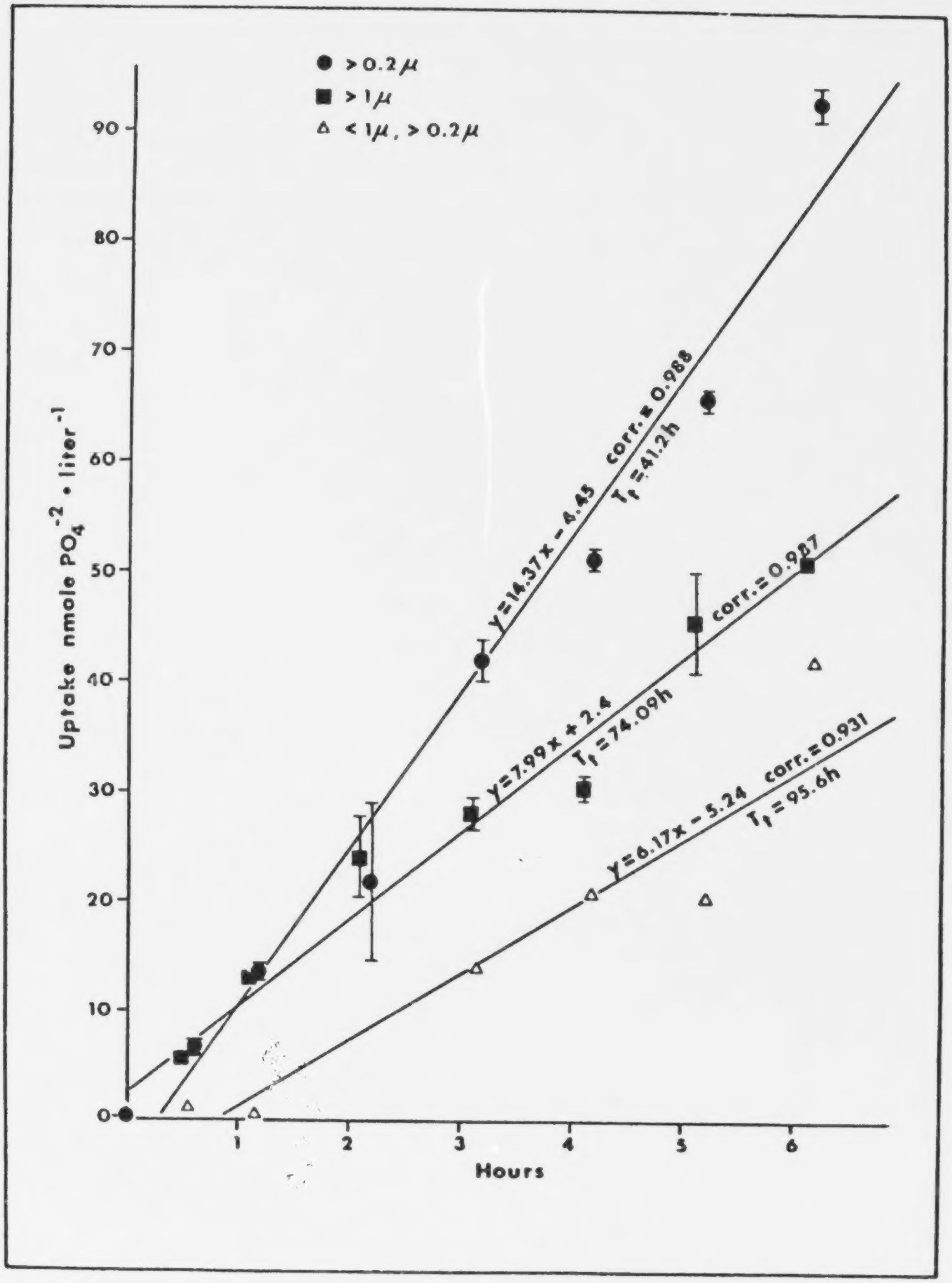


Figure 1. Kinetics of orthophosphate uptake by three particulate size classes at station A2, 7-5-78. The sample was collected at 1 m below the surface where the [PO_4^{-2}] = 0.59 μmole·liter^{-1}. $H_3{}^{33}PO_4$ was used as the tracer. Symbols and bars represent the mean and ranges of duplicate determinations. Total uptake (>0.2 μm particle size): ●; uptake by the >1.0 μm size class: ■; bacterioplankton uptake (<1.0 μm, >0.2 μm particle size): Δ.

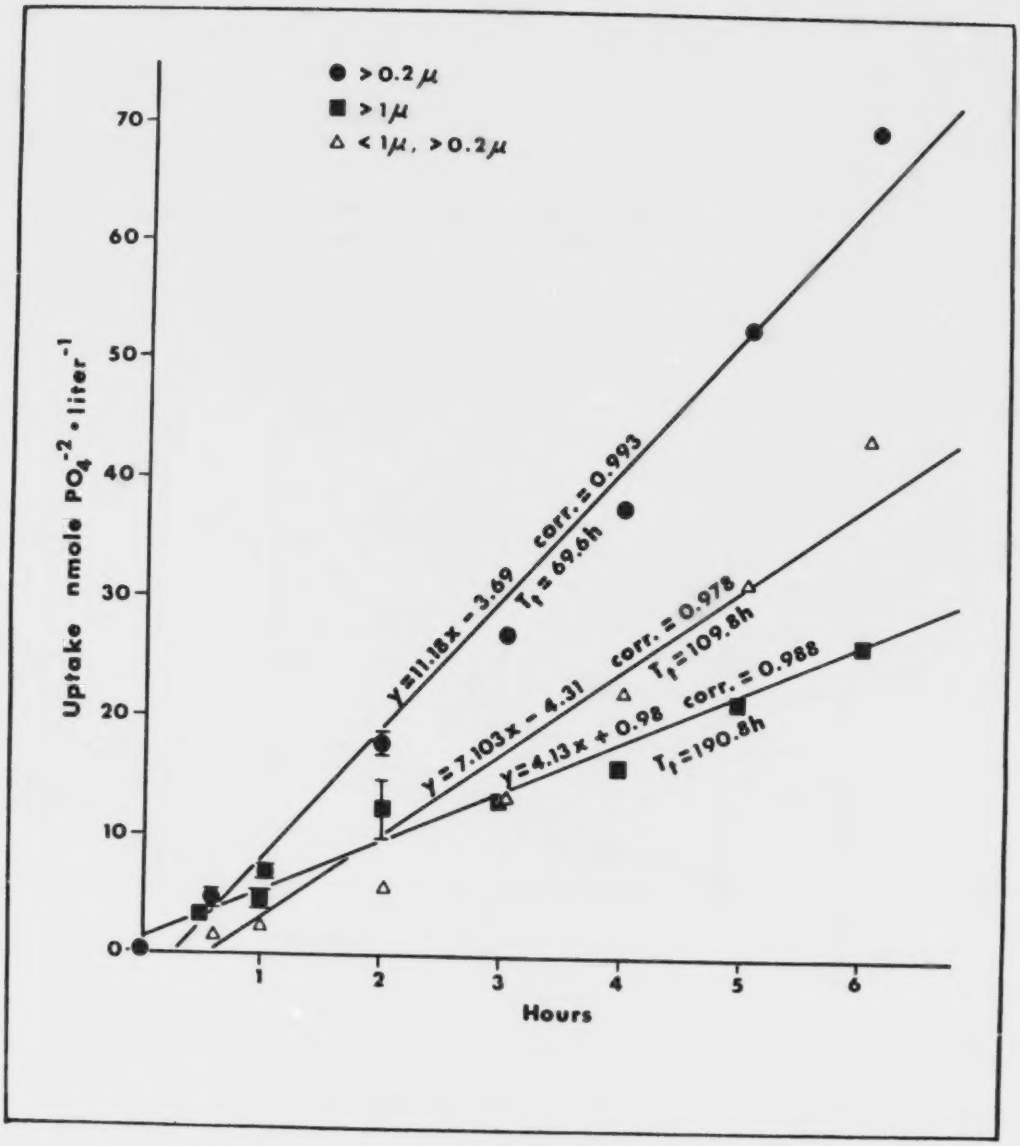


Figure 2. Kinetics of orthophosphate uptake by 3 particulate size classes at station A0, 7-5-78. The sample was collected at 1 m below the surface; [PO$_4^{-2}$] = 0.78 μmole·liter^{-1}. $H_3{}^{33}PO_4$ was used as the tracer. Symbols and bars represent the mean and ranges of duplicate determinations. Total uptake (>0.2 μm particle size): ●; uptake by the >1.0 μm size class: ■; bacterioplankton uptake (<1.0 μm, >0.2 μm particle size): △.

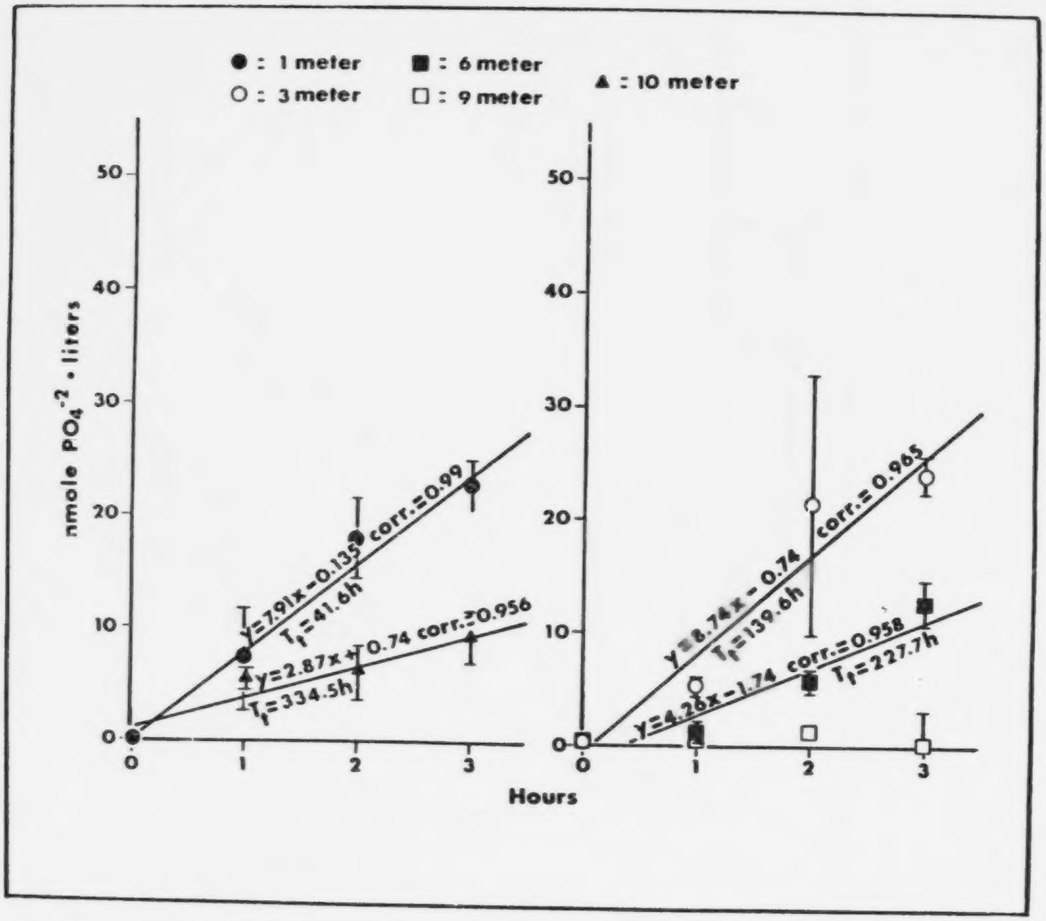


Figure 3. Kinetics of orthophosphate uptake by the total microbial populations at 5 depths at station A2, 8-16-78. $H_3{}^{32}PO_4$ was used as the tracer. Symbols and phosphate concentrations at each depth: 1 m - 1.12 µmole $PO_4{}^{-2}\cdot liter^{-1}$, ●; 3 m - 1.22 µmole $PO_4{}^{-2}\cdot liter^{-1}$, ○; 6 m - 0.97 µmole $PO_4{}^{-2}\cdot liter^{-1}$, ■; 9 m - 0.88 µmole $PO_4{}^{-2}\cdot liter^{-1}$, □; 10 m - 0.96 µmole $PO_4{}^{-2}\cdot liter^{-1}$, ▲.

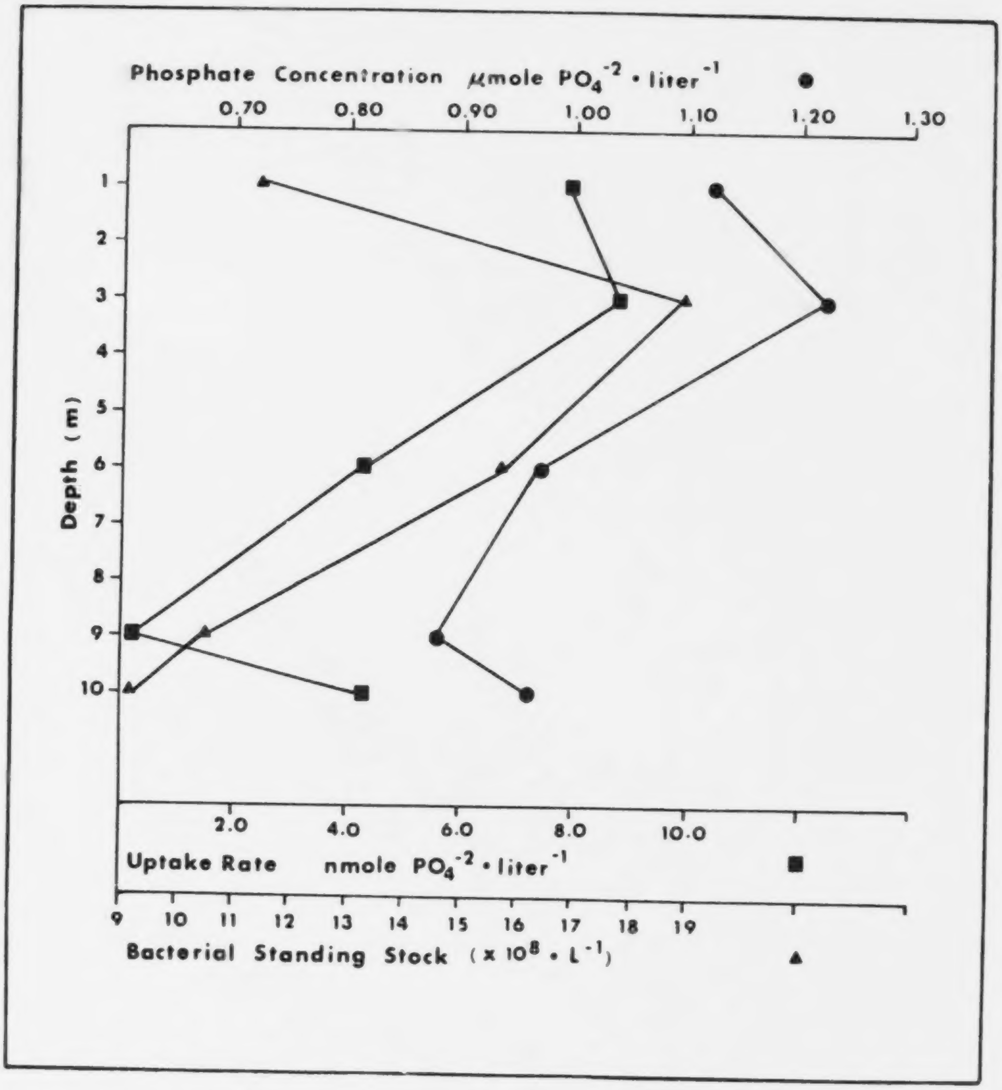


Figure 4. Depth profile of bacterial numbers (▲), phosphate concentrations (●) and uptake rates (■) at station A2, 8-16-78. $H_3{}^{32}PO_4$ was the tracer. Rates are slopes of the kinetics of orthophosphate uptake by the total microbial populations at 5 depths. Bacterial numbers are from direct counts by epifluorescent microscopy.

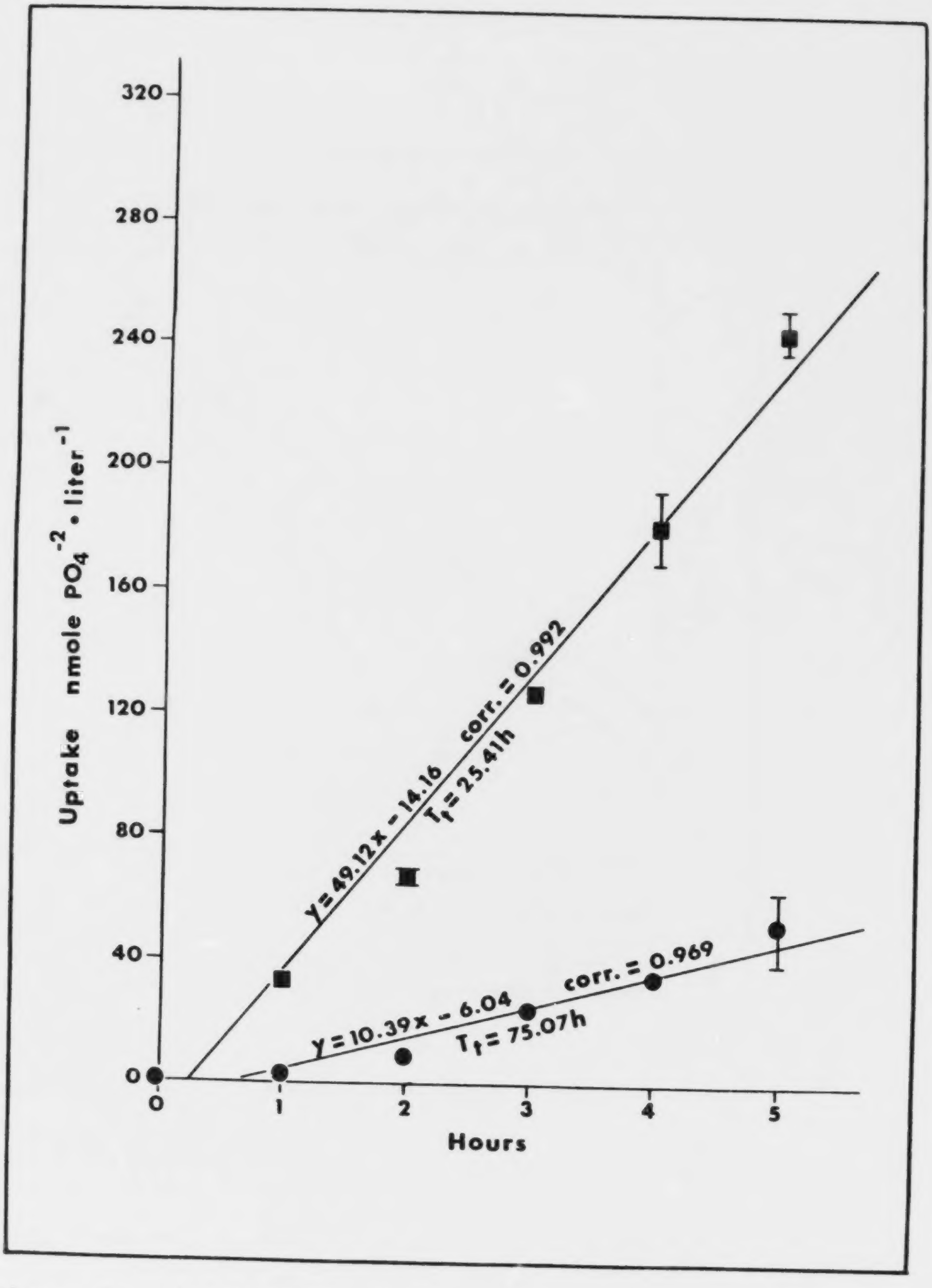
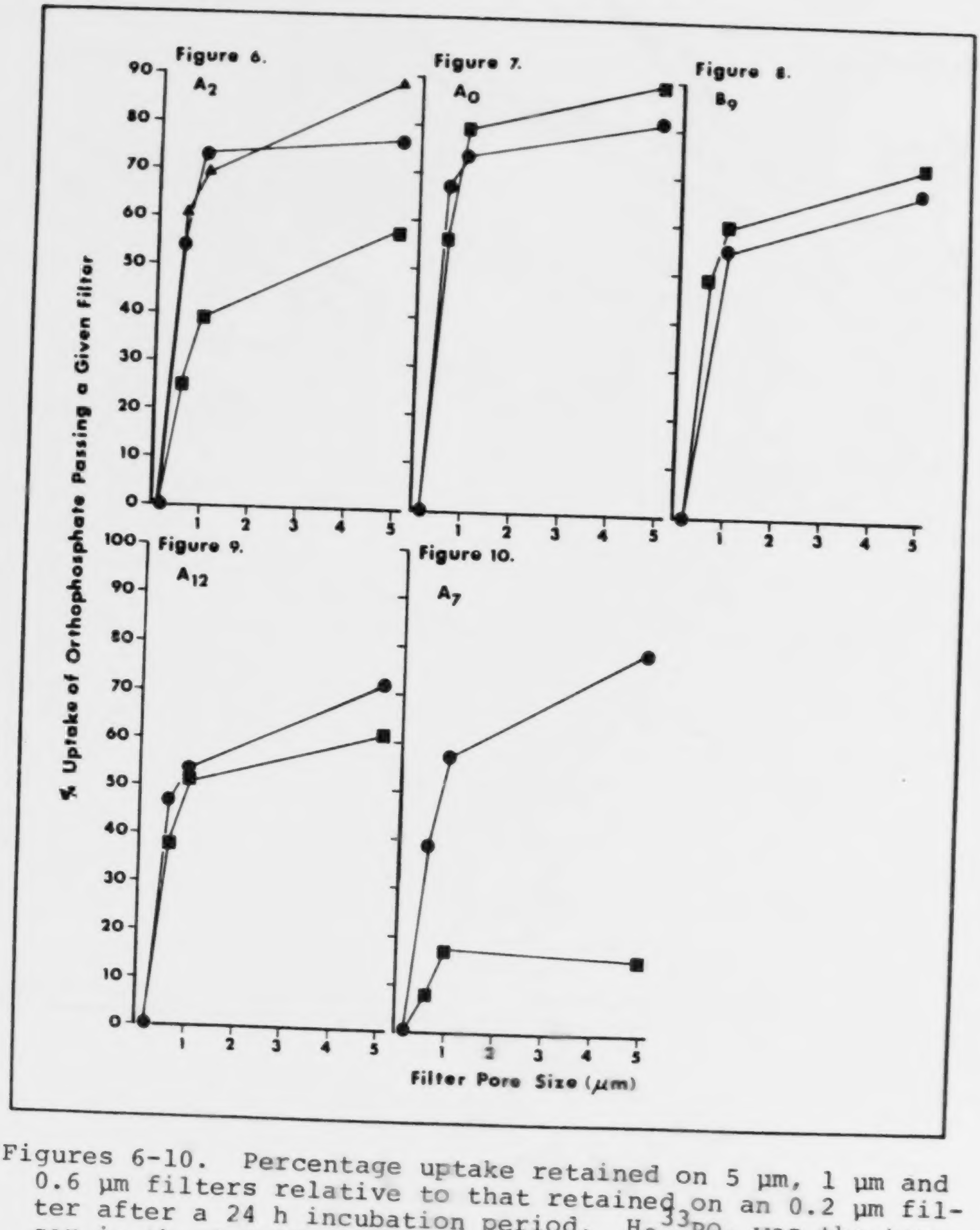


Figure 5. Kinetics of orthophosphate uptake as retained on an 0.2 µm pore size filter at station A2 and A0, 9-6-78. Samples were collected from 1 m below the surface. $H_3{}^{32}PO_4$ was used as the tracer. Phosphate concentrations were 0.78 µmole $PO_4{}^{-2}$·liter^{-1} at A0 (●) and 1.25 µmole $PO_4{}^{-2}$·liter^{-1} at A2 (■).



Figures 6-10. Percentage uptake retained on 5 μm, 1 μm and 0.6 μm filters relative to that retained on an 0.2 μm filter after a 24 h incubation period. $H_3{}^{33}PO_4$ was the tracer in the 7-5-78 experiments (●), $H_3{}^{32}PO_4$ was used in the 8-16-78 experiment at station A2 (▲) and in the 9-6-78 experiments (■). All samples are collected from a depth of 1 m below the surface.

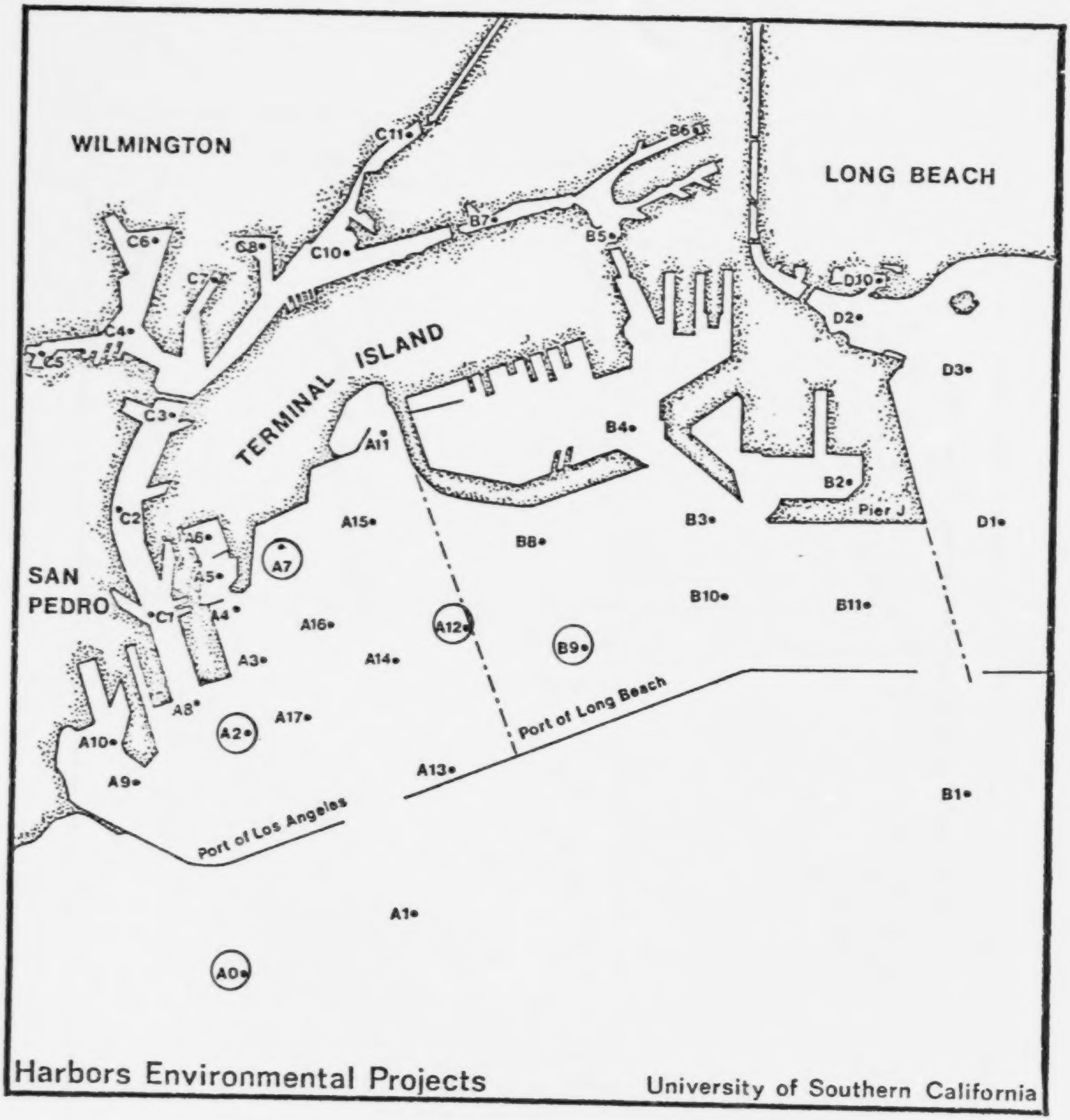


Figure 11. Stations for Orthophosphate Study

COMMUNITY METABOLISM OF TOTAL ADENYLATES BY THE MICROHETEROTROPHS OF THE LOS ANGELES HARBOR AND SOUTHERN CALIFORNIA COASTAL WATERS

INTRODUCTION

The radiotracer method for studying uptake kinetics by natural populations of aquatic microheterotrophs (Wright and Hobbie, 1966; Hobbie and Crawford, 1969) has yielded considerable information on the turnover times and relative uptake rates of various dissolved organic substrates. When combined with a direct measurement of the natural substrate concentration, this kinetic approach can establish more precise values of uptake velocity. If the standing stock of microheterotrophs is also measured, the specific activity of a given population for uptake of a particular compound can be calculated. Wright (1978) has suggested three specific activity indices: V_{max}, as $10^{-12}\mu g \cdot h^{-1} \cdot cell^{-1}$; turnover rate ($T_r$), as $10^{-6} \cdot h^{-1} \cdot cell^{-1}$ liters; and direct uptake rate, V_n, as $10^{-12}\mu g \cdot h^{-1} \cdot cell^{-1}$. Data reported as a specific activity allow one to make direct comparisons among aquatic heterotrophic systems, whether they vary in space or time. The purpose of this study was to compare seasonal variations in uptake activity by the bacterioplankton of the Los Angeles Harbor with the activity in the contiguous coastal waters.

The adenylate system is well suited as a study of microbial activity, since the adenylates occur as universal components of all living cells, both in stable macromolecules like DNA and RNA and as major chemical species involved in cellular energy metabolism. Furthermore, adenylates can be measured in nanomolar concentrations in the ocean, by means of the sensitive luciferin-luciferase assay (Holm-Hansen and Booth, 1966); Hodson, *et al.*, 1976). Previously, dissolved ATP has been shown to occur in the ocean at concentrations ranging from 0.1 to $0.6\mu g \cdot liter^{-1}$, where it is rapidly utilized by marine bacteria (Azam and Hodson, 1977).

^3H-AMP is employed as a tracer of TA metabolism by microheterotrophs in the present study. Its specific activity was calculated on the basis of the total dissolved adenylate concentration (TA = ATP + ADP + AMP), since it is probable that all adenylates share the same transport system (Martin and Demain, 1977). However, this assumption will soon be tested under controlled conditions with bacterial isolates from the harbor.

This report attempts to correlate direct counts of bacterioplankton standing stocks and measurements of natural adenylate concentrations with the kinetics of TA uptake during three seasons of the year (summer, fall and winter, 1978; the annual cycle will be completed by spring sampling in March, 1979) at a sampling station (A2) inside the Los Angeles Harbor and one (A0) outside the breakwater in coastal waters. Previous studies for the uptake of other dissolved organic substrates (*e.g.*, ^{14}C-glycine, ^{14}C-amino acid mixture, ^{14}C-glucose) have shown a 5- to 20-fold difference in uptake, on a relative basis, between these stations; however, this is the first time that uptake of a single compound has been followed continuously over an annual cycle in conjunction with measurements of its *in situ* concentration.

METHODS

Seawater samples were collected by Niskin sterile-bag devices from 1 meter below the surface and maintained within 2°C of the *in situ* temperature until return to the laboratory, where they were filtered through a 203µm Nitex net to remove larger plankton. All other filtrations employed discrete pore-size membrane filters (Nuclepore, 47mm diameter) which are hereafter designated simply as x µm filters, where x is 0.2, 0.6, 1 or 5µm and indicates the diameter of the pores. The samples were stored at 18°C and assayed within 2 hours of return to the laboratory.

Extraction and measurement of ATP and TA were according to the procedure of Holm-Hansen and Booth (1966) as modified by Azam and Hodson (1977) and Karl and Holm-Hansen (1978). The dissolved TA concentration is defined as that passing an 0.2µm filter. The particulate TA of size fractions 0.2µm to 1.0µm and 0.2µm to 203µm were estimated by measuring the 1µm and 203µm filterable TA, respectively, then subtracting the average TA of the dissolved fraction.

Determination of bacterial and phytoplankton standing stocks were by the acridine orange direct counting technique (AODC) according to Daley and Hobbie (1978) and chlorophyll *a* biomass estimates by the fluorometric technique of Strickland and Parsons (1972).

Two different types of uptake experiments were performed. For simple kinetics, uptake of label over time was studied. For Michaelis-Menten (M-M) kinetics, varying concentrations of cold AMP were added to different assay flasks and the velocity of uptake at each substrate concentration was determined from a single point incubation. Zero hour (t_o) and acid-killed controls did not yield significantly different values and were generally less than 10% of the uptake of label after 2.5 hours incubation for any substrate concentration. For convenience, t_o blanks were prepared for the simple kinetic experiments, while acid-killed controls were employed in the M-M kinetics experiments. Subtraction of these blanks eliminates nonbiological phenomena such as adsorption and background radiation from inclusion in the uptake data.

the uptake data.

For the measurement of simple uptake kinetics, 50 µCi ^{3}H-AMP (15 Ci·mmole^{-1}) were added to 500ml seawater sample and incubated with stirring at 18°C. Duplicate 10ml samples were removed at half-hour or hourly intervals for up to 7 hours and passed through an 0.2µm filter. The filter was rinsed twice with 5ml of 0.2µm prefiltered sea water (SW), dried for one hour under an IR lamp, and placed in 10ml of a toluene-based fluor for counting in an LS-100 liquid scintillation system.

In the first experiment (June 7, 1978) incorporation of label into macromolecules was measured by following the filtration of duplicate 10ml samples with two 5ml rinses of OC 0.5N PCA prior to the SW rinses. In the second experiment (August 2, 1978) duplicate 10ml samples were passed through 1.0µm filters so that kinetics of uptake by the >1.0 µm size class, and by subtraction, by the >0.2µm, <1.0µm size class of microheterotrophs, could be followed in addition to total uptake.

For the M-M kinetic experiments, 10ml aliquots of sample were dispensed in duplicate into sterile serum bottles (100ml capacity) to which a 1ml volume of substrate containing 1 µCi ^{3}H-AMP and varying concentrations of cold AMP was added, for a final concentration of 6 to 100 nmole TA·liter^{-1}. In the last experiment (December 6, 1978) the addition of ^{3}H-AMP was reduced to 0.1 µCi to yield a low concentration of 0.6 nmole TA·liter^{-1}. After a 2.5 hour incubation (2 hours at A2 and 5 hours at A0 on December 6, 1978), the samples were taken through the filtration procedure described above. Acid-killed controls, to which the addition of 0.02ml of a 7% PCA solution immediately preceded the addition of label, were filtered after the same incubation period. In the first two experiments, controls were prepared only for the lowest and highest substrate concentrations; thereafter they were prepared for all concentrations.

For the size-fractionation studies, 100ml of water sample were incubated with 10 µCi of ^{3}H-AMP at 18°C for endpoint determination of the uptake rate by four size classes of microheterotrophs. Acid-killed controls were prepared for each sample. After 24 hours (4h at A0 and 2h at all other stations on December 6, 1978) duplicate samples were removed for filtration through 5.0, 1.0, 0.6 and 0.2 µm filters, and treated as described above.

Data Calculations

Conversion of counts per minute (cpm) to disintegrations per minute (dpm) was by means of a quench curve relating external standard ratio to counting efficiency. Specific activity of the label was calculated, based on the sum of the added ^{3}H-AMP and the natural TA concentration in the seawater sample. One ml aliquots of sample plus label were counted directly in Aquasol to determine total dpm (^{3}H-AMP)·ml^{-1} of sample.

For the simple kinetic studies, uptake values, as nmole TA·liter^{-1}, were plotted against incubation time. The potential uptake rate (V_p), at the elevated (TA + ^{3}H-AMP) adenylate concentration, is the slope of the line determined by linear regression analysis, and is given as nmole TA·liter^{-1}·h^{-1}. The specific potential uptake rate (V_{ps}) is determined as the uptake rate per 10^9 bacterial cells (by AODC). The turnover time (T_t) for this elevated TA concentration is determined as the quotient of the rate (V) divided into the sum of the natural TA + ^{3}H-AMP concentrations.

For analysis of the M-M kinetic data, the uptake rate at each concentration of substrate was plotted against substrate concentration to determine whether saturation kinetics occurred. A Woolf transformation of this data, to an S/V *vs* S plot, yields a straight line with the equation

$$S/V = S/V_{max} + K_t/V_{max}$$

where

K_t = a concentration constant similar to the Michaelis constant K_m = the negative abscissa intercept

V_{max} = a velocity constant observed when a limiting step is saturated with substrate = the inverse of the slope

S = substrate concentration

S/V = the turnover time for substrate at each concentration

The turnover time (T_t) at the natural TA concentration, is the time required for the microheterotrophs to remove all adenylates from solution (assuming no further input) and is determined as the ordinate intercept of the Woolf plot. Turnover rate (T_{rn}) is the inverse of T_t and is reported here on a per cell basis, as suggested by Wright (1978), as 10^{-6}·h^{-1}·cell^{-1}·liter^{-1}. The uptake rate at the natural concentration of substrate, V_n, was calculated by substituting the natural TA concentration for S in the equation above, and solving for V. Specific uptake rate at the natural concentration (V_{ns}) was calculated as nmole TA·10^9 cells^{-1}·h^{-1} (cell number from AODC). V_{max} was also calculated on a per cell basis.

For analysis of the endpoint size fractionation data, uptake rates were calculated for each size class as nmole TA·liter^{-1}·h^{-1}. The percent uptake passing a given filter porosity was determined, assuming a 100% retention by the 0.2µm filter.

RESULTS

The uptake of dissolved ^{3}H-AMP was studied in June, August and December, 1978 at station A0 and October as well at station

A2 in the Los Angeles Harbor. The dissolved natural TA concentration ranged from 1.19 to 1.74 nmole TA·liter^{-1} at station A0 and from 1.53 to 4.96 nmole TA·liter^{-1} at A2 for these months, while the particulate TA concentration (>0.2μm, <203 μm) ranged from 1.89 to 5.75 nmole TA·liter^{-1} and from 3.47 to 19.8 nmole TA·liter^{-1}, respectively, at A0 and A2 (Table 1).

The kinetics of ^{3}H-AMP uptake was linear over 7 hours at both stations, as shown in Figures 1-3. At station A2, potential uptake velocities per liter of water were high in June and August compared with uptake in December, at 1.08, 0.87 and 0.2 nmole TA·liter^{-1}, respectively. However, on a per cell basis these values become 0.57, 0.49 and 0.43 nmole TA·10^{9} cell^{-1}·h^{-1}, with a variance less than 25% among them. The bacterial standing stocks are shown in Table 2. Specific potential uptake rates at A0 are less than half those at A2 on the same sampling date. This difference is greatest in August, when the potential uptake rate at A2 is 10 times as high as at A0 (Table 3, 12th column).

Turnover times likewise show wider disparities among sampling dates at a given station than do turnover rates, which are reported on a per cell basis. The longest turnover time occurred at A0 in August, at 258 h, while the shortest was at A2 in June at 10 h. These differences become much smaller when expressed as turnover rates of 6.1·10^{-6}·h^{-1}·cell^{-1}-liters and 54.3·10^{-6}·h^{-1}·cell^{-1}-liters, respectively. The dissolved TA concentration at A0 was, on the average, 60% lower than at A2 and varied less than 20% from its average value of 1.45 nmole TA·liter^{-1}. The December adenylate concentration at A2 was only 40% of the mean value of 3.69 nmole TA·liter^{-1} over these three months.

The rate of incorporation of ^{3}H-AMP is not significantly different from that of uptake; at neither station do these rates differ by more than 0.003 nmole TA·liter^{-1}·h^{-1}. After five hours of incubation, over 96% of the assimilated label is apparently incorporated into macromolecules; soluble pools must be quite small. Azam and Hodson (1977) reported a 98% assimilation of ^{14}C-ATP uptake in the Saanich Inlet, British Columbia, indicating that little is respired. Assuming that respiration is also negligible in this system, it is concluded that over 90% of the adenylates transported across the cell membrane result in macromolecular incorporation.

In August (Figure 2) we examined the uptake kinetics of ^{3}H-AMP into two size fractions. A surprisingly high (33-49%) percentage of total uptake was associated with the size class >1.0μm, presumably containing phytoplankton, microzooplankton and bacteria attached to particles. This contrasts with the predominance (80-90%) of uptake by the size class >0.2μm, <1.0μm ≡ bacterial, for ^{14}C-glucose, a ^{14}C-amino acid mixture from algal hydrolysate, and ^{3}H-thymidine, as found in an earlier study (Sullivan, *et al.*, 1978) and for dissolved glucose, serine, acetate and AMP in sea water (Azam and Hodson, 1977).

The results of the single point size fractionation studies (Figures 4 and 5) show that the microheterotrophs in the size fraction <1.0μm generally accounted for more than 75% of the ^{3}H-AMP uptake. However, in June and August, months immediately preceding phytoplankton blooms, this fraction contained 40 to 50% of the ^{3}H-AMP taken up. By contrast, this fraction only contains between 10 and 30% of the particulate adenylates (Table 1).

Figures 4-7 show the results of the multiconcentration experiments for ^{3}H-AMP uptake at stations A2 and A0. Addition of cold AMP plus ^{3}H-AMP to the samples resulted in concentrations ranging from 0.4 and 1.6 times that of the natural adenylate concentration to concentrations two orders of magnitude greater. The shape of the S *vs* V plot varied from month to month at station A2 (Figures 4 and 5a and b). In June and October an initial saturation seems to be followed by a possible second increase in uptake at higher substrate concentrations. This was not the case in August, when at very high concentrations the ^{3}H-AMP uptake rate decreased with increasing S, or in December, where the plot is more linear than hyperbolic.

Woolf transformations of these data into S *vs* $S_{/V}$ plots are shown in Figures 6 and 7. All plots were linear, with correlation coefficients >0.88 at the $\alpha = 0.01$ level. In the Woolf transformation of the August experiment (Figure 6b) the line was calculated for all concentrations but the two highest; as inclusion of the latter points would have resulted in a negative turnover time. These points (circled in Figure 6b) correspond to the rate decrease in Figure 5a and are considered to have arisen from experimental error.

It is constructive to note the behavior of the S *vs* $S_{/V}$ plots as they near the ordinate axis. At station A2 in June, August and October (Figure 6) the $S_{/V}$ values at the lowest concentrations (single point turnover times) are greater than the value of the ordinate intercept (multiconcentration turnover time). This conforms to the theoretically ideal situation, and is what can be expected in eutrophic waters (Gocke, 1977), such as occur in the Los Angeles Harbor. However, in the December experiments at both stations A0 and A2, the $S_{/V}$ values curve towards the abscissa axis at lower concentrations. Apparently, this phenomenon is often associated with more oligotrophic waters, where uptake by a heterogeneous population results in computation of longer turnover times by the multiconcentration method (Williams, 1973). December is the winter season in the harbor and both the bacterioplankton population and *in situ* adenylate concentrations are <25% of their October values at station A2. This is consistent with multivariate benthic and plankton analyses, where outside station A1 and outer harbor stations cluster together in December, but are separate the rest of the year. Station A0 is just outside the harbor breakwater and even in summer months is characterized by lower microbial standing stocks and nutrient levels than occur inside the harbor (Tables 2 and 3).

The uptake constants K_t and V_{max} are summarized for each experiment in Table 3. V_{max} values ranged from 0.3 nmole TA·10^9 cells^{-1}·h^{-1} at station A2 in October to almost 2.0 nmole TA·10^9 cells^{-1}·h^{-1} at station A2 in June and December. K_t values ranged from a high of 105 nmole TA·liter^{-1} at station A2 in December to a low of 11.9 nmole TA·liter^{-1} at A2 in October.

Turnover times determined both by simple and M-M kinetics are also compared in Table 3. The former method yielded values 30 to 65% lower than did the latter, except in August. Part of the explanation for this finding is the difference in uptake rate over seven hours as opposed to the first two hours of incubation; both have correlation coefficients of >0.90, but the initial uptake rate is only about half the rate over seven hours. When turnover time is calculated on this lower rate of uptake, the result is much closer to that calculated from M-M kinetics, where the incubation period was 2-5 hours.

The rate of uptake of dissolved ^{3}H-AMP at the natural TA concentration (V_n) as calculated from M-M kinetics, is shown in the last two columns of Table 3. Unlike the potential uptake rate (V_p), which showed little seasonal variation on a per cell basis, the specific V_n rates vary tenfold, from 0.29 to 0.025 nmole TA·10^9 cell^{-1}·h^{-1} in August and December, respectively.

Bacterioplankton and phytoplankton standing stock (biomass) values are shown in Table 2. Note that the bacterial biomass at station A2 is, on the average, almost three times that at station A0. Phytoplankton standing stocks remain fairly constant except in July, when a bloom occurred at all stations, and in September, when a second bloom occurred in patches in the harbor. The bacterioplankton increase, apparently in response to these blooms, peaked in July and October. Total particulate adenylate concentrations (Table 1) at stations A0 and A2 peaked around June-July and in September. Approximately 80% of the total particulate adenylate is found in the size fraction >1.0μm throughout the period sampled.

DISCUSSION

Microheterotrophic activity in the Los Angeles Harbor and coastal waters is high, with V_{max} values ranging from 0.35 to 3.7 nmole TA·liter^{-1}·h^{-1} (0.13 to 1.3 μgC·liter^{-1}·h^{-1}). The magnitude of these V_{max} values is typical of highly eutrophic waters, comparable to those found for glucose and leucine, 1.86 and 0.34 μgC·liter^{-1}·h^{-1}, respectively, in the Kiel Fjord (Gocke, 1977) and higher than those measured in Lake Erken for glucose, where V_{max} values range from 0.009 to 0.072 μgC·liter^{-1}·h^{-1} (Wright and Hobbie, 1966). The dissolved adenylate concentration is also high compared to other oceanic measurements, *e.g.* dissolved ATP ranged from 0.22 to 2.90 nmole·liter^{-1} (118 to 1557 ng ATP·liter^{-1}) at stations A0 and A2 between April and December, 1978. This is comparable to the average dissolved ATP concentration of 466 ng·liter^{-1} in the eutrophic waters of Saanich Inlet, British Columbia and of 218 ng·liter^{-1} off the SIO pier at San Diego (Azam and Hodson, 1977).

Since a minimum of 90% of adenylate uptake apparently results in incorporation into acid insoluble material (presumably macromolecules), the uptake kinetics for this substrate reflect on both the activity and growth potential of a population. A comparison of the potential (V_p) and actual (V_n) uptake rates at A2 (Table 3) reveals that, on a per liter basis, both show substantial decreases in adenylate uptake from summer to winter. V_p ranges five-fold, from 1.08 to 0.2 nmole TA·liter^{-1}·h^{-1} while V_n ranges forty-fold, from 0.51 to 0.013 nmole TA·liter^{-1}·h^{-1}. However, when the V_{ps} and V_{ns} are considered, a different result emerges. Whereas V_{ps} differs little between June and December, at 0.57 and 0.43 nmole TA·10^9 cell^{-1}·h^{-1}, respectively, V_{ns} still varies tenfold, from 0.29 to 0.025 nmole TA·10^9 cell^{-1}·h^{-1}.

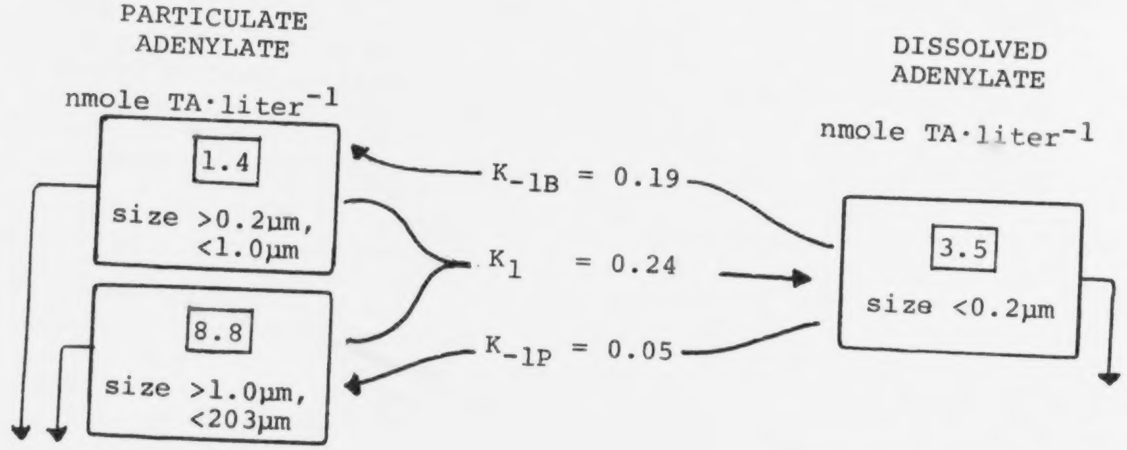
These data indicate that, while potential uptake activity changes primarily as a function of the microheterotrophic population size, uptake rate at the *in situ* substrate concentration varies in a more complex way annually. The tenfold difference still seen between summer and winter V_{ns} rates may be due in part to subtle differences in the dissolved TA concentrations on which these rates are based. Whereas the natural adenylate concentration at A2 decreased 3-fold, from 4.96 to 1.53 nmole TA·liter^{-1} in August and December, respectively, the elevated concentrations for which V_p values are measured vary less than 1.5-fold over this period.

When similar comparisons are made between the V_p rates at A0 and A2, it can be seen that the V_{ps} at A0 is 2- to 10-fold lower than at A2 on a given sampling date; the widest disparity in V_{ps} values occurs in August. Unfortunately, M-M-type kinetic experiments were unsuccessful at A0 in June and August; therefore only in December can V_n comparisons be made between the stations. The V_{ns} at A0 was 0.014 nmole TA·10^9 cell^{-1}·h^{-1}, a little over one-half that at A2 (0.025 nmole TA·liter·10^9 cell^{-1}·h^{-1}). This indicates that the bacteria outside the breakwater are both potentially and actually less active in the uptake of ^{3}H-AMP than are those inside the harbor, even when the bacterioplankton densities are very similar at the two stations, as they are in December (Table 2). This observation could be due to a number of causes, such as different species compositions, different transport capabilities, inducible transport systems, or a higher percentage of dormant cells outside the breakwater.

The V_{max} would be expected to vary seasonally in agreement with the V_p rates. Specific V_{max} values vary about 2-fold at A2, which corresponds to the low specific V_p variation at this station. The December V_{max} value at A2 is about four times that at A0 in this month; the difference in their V_p values is 3-fold.

The turnover rate per cell is another measure of activity, one that is strongly dependent upon the rate of substrate input, of which we have no measure in this study. Although a linear rate of uptake was assumed from a steadily diminishing pool of the dissolved ^{3}H-AMP in this study, a rapid cycling of nutrients might actually have been missed in the closed environment of our flask. However, the brevity of the incubation periods compared with the uptake rates measured indicates this is unlikely.

In the natural environment even less is known about the rates of processes, such as grazing, excretion and cell lysis, which lead to an input of TA into the dissolved fraction from particulate matter. If a steady state is assumed for the particulate and dissolved adenylate concentrations at A2 from average values measured in this study, a first approximation can be made of the rates between pools in the adenylate system, as diagrammed below:



Rates K_1, K_{-1B}, K_{-1P} are in units nmole TA·liter^{-1}·h^{-1}.

K_1 = rate of input of adenylates into the dissolved pool from the particulate fractions

K_{-1B} = uptake rate of dissolved adenylates by the bacterioplankton (<1.0µm size fraction)

K_{-1P} = uptake rate of dissolved adenylates by the >1.0µm size fraction

Assuming that a steady state exists for particulate and dissolved adenylate concentrations, then $K_1 = K_{-1} = K_{-1B} + K_{-1P}$.

K_{-1} is assigned the average V_p value from measurements in this study of 0.24 nmole TA·liter^{-1}·h^{-1}. Since the size fractionation data indicated that 50 to 90% of heterotrophic uptake of ^{3}H-AMP is associated with organisms passing a 1.0µm filter, a value of 80% the K_{-1}, or 0.19 nmole TA·liter^{-1}·h^{-1} is assigned as K_{-1B}, leaving 0.05 nmole TA·liter^{-1}·h^{-1} as K_{-1P}. Thus, $K_1 = K_{-1} = K_{-1B} + K_{-1P}$ =0.24 nmole TA·liter^{-1}·h^{-1}. When this rate is divided into the particulate adenylate concentration, a turnover time of 43 hours is estimated for particulate adenylates in the Los Angeles Harbor. The flux of particulate adenylates into the dissolved adenylate pool is the sum of many processes, major ones being excretion, decomposition and grazing, with cell lysis and leakage being less important.

Although information is too limited to subdivide the K_1 flux, it is clear that the bacterioplankton predominate in the uptake of dissolved adenylates. From the kinetic experiment in which adenylate uptake was fractionated, V_p values for the >0.2µm, <1.0µm size class and >1.0µm size class were 0.46 and 0.42 nmole TA·liter^{-1}·h^{-1}, respectively. If we assume that all the uptake by the larger size class is algal, an all the uptake by the smaller size class is bacterial, then specific V_p values for this experiment are 0.0006 and 0.032 nmole TA·µgC·h^{-1}, respectively. Thus, the bacterioplankton uptake exceeds the phytoplankton uptake rate by 55 times, on a per biomass basis, although the two are of equal magnitude on a per liter basis. This comparatively high uptake by the larger size class may alternatively be interpreted as being primarily due to bacteria attached to particles. Particulate organic matter may have been relatively high at the time of this sampling (August) following the July bloom of *Nitzschia seriata* throughout the harbor.

Although no estimate can be made of the relative rates of input into the dissolved TA pool from the two particulate size classes, it can be noted that the standing stock of the larger size class is 6 times that of the <1.0µm size class. This indicates the formation of particulate adenylates by other means than through uptake of dissolved adenylates. Of course, the major processes of grazing, photosynthesis, and biosynthesis have been omitted from the overly simplified budget.

A comparison of the natural dissolved TA concentrations (which range from 1.53 to 4.96 nmole TA·liter^{-1}) with the K_t values derived from M-M kinetics (which range from 11.9 to 105 nmole TA·liter^{-1}, Table 3) indicates that the microheterotrophs in these waters are always substrate-limited for TA; their uptake rate at the natural concentration being 1 to 30% of the potential V_{max} rate at saturating levels of TA. These extremes occur in December and August, respectively, months in which the disparities between the natural TA concentrations and the K_t values are greatest and least, respectively. The K_t value at station A0 in December is only 40% that at A2, which indicates that the bacteria outside the harbor may have a higher affinity for their substrate in partial compensation for their lower activity.

SUMMARY

The following summarizes the results of a study on the *in situ* concentrations and uptake rates for dissolved total adenylates (TA = ATP + ADP + AMP) by the microheterotrophs of the Los Angeles Harbor and coastal waters.

1. The natural TA concentration at station A2 inside the harbor ranged from 1.5 to 5.4 nmole TA·liter^{-1}, whereas the K_t value ranged from 11.9 (August) to 105.4 (December) nmole TA·liter^{-1}. At station A0 outside the breakwater, dissolved TA concentration ranged annually from 1.2 to 2.2 nmole TA·liter^{-1}; the K_t value for December was 41.8 nmole TA·liter^{-1}. These data indicate that the transport system of microheterotrophs for adenylate uptake is always undersaturated in these waters.

2. V_{max} and V_p values are similar in measuring the potential rates of uptake a population shows for substrate concentrations above the *in situ* level. At station A2 these rates vary seasonally by 4- and 5-fold, respectively, when expressed as nmole TA·liter·h^{-1}. When expressed on a per cell basis, however, the annual variation is 2-fold or less. These data indicate that uptake potential is directly correlated with the number of bacteria present.

3. V_p, the potential uptake rate, is 2 to 10 times greater than the uptake rate at the natural substrate concentration, V_n, which is derived from M-M kinetics. Specific V_n varies 10-fold between August and December at A2, which indicates that the actual uptake activity of the microheterotrophs at the natural substrate concentration varies on a seasonal basis. It seems more likely that this variation would be due to subtle differences in *in situ* TA concentration than to temperature effects, since all experiments were carried out at 18°C, and since V_p values would be equally expected to vary with differences in temperature.

4. The specific V_p at A0 is 2- to 10-fold lower than at A2 on a given sampling date and the specific V_n for December at A0 is only half that at A2. This indicates that the bacteria outside the harbor breakwater are less active in the uptake of adenylates than are those inside the harbor, which could be explained by differences in species composition, transport capabilities for the adenylates, or metabolic status of the populations.

5. A simple budget was made for the TA flux between the

dissolved and particulate pools in the harbor. Assuming a steady state concentration of 10.2 nmole TA·liter^{-1} particulate adenylates and 3.5 nmole TA·liter^{-1} dissolved adenylates, the rate of input of particulate TA into the dissolved fraction is equal to the rate of uptake of dissolved adenylates into the particulate fraction, 0.24 nmole TA·liter^{-1}·h^{-1}. Such complex processes as grazing, leakage, excretion, and cell lysis are lumped together here as potential sources of the dissolved TA.

6. Size fractionation studies indicate that approximately 20% of the particulate adenylate concentration is found in the >0.2, <1.0μm size class, which generally accounted for 75% of the ^{3}H-AMP uptake. This shows that bacterioplankton are predominant in the uptake of dissolved TA; however, in June and August, months which immediately preceded phytoplankton blooms, only 40 to 60% of the uptake passed a 1.0μm filter, which suggests that phytoplankton may also be active in uptake at this time.

LITERATURE CITED: See Section VI.

Table 1. Dissolved and particulate TA concentrations in the Los Angeles Harbor and coastal waters

Sampling date	Size fraction			Station		
		A0	A2	A7	A12	B9
		Total adenylates (nmole·liter^{-1})				
6-7-78	<0.2μ	1.74	3.97±1.21	4.29±0.16	4.14±0.41	3.09±0.16
	0.2μ-1.0μ*	0.33±0.7	1.23±0.34	-	0.49±0.4	2.04±0.30
	0.2μ-203μ	5.75±0.6	19.8±3.3	25.6±5.3	3.48±0.11	14.8±4.0
	1.0μ-203μ	5.4	18.6		3.0	12.8
8-2-78	<0.2μ	1.41	4.96±0.48	6.24±1.05	2.27±0.12	2.35±0.13
	0.2μ-1.0μ	0.75±0.03	1.89±0.51	7.89	2.81±1.03	-
	0.2μ-203μ	2.45±1.48	6.10±0.10	24.2±1.0	8.21±1.19	3.78±0.30
	1.0μ-203μ	1.7	4.2	16.3	5.9	
12-6-78	<0.2μ	1.19±0.10	1.53±0.45	2.35±0.52	1.70±1.23	1.76±0.17
	0.2μ-1.0μ	0.17±0.17	1.08	0.94±0.50	0.64±0.34	3.71±0.35
	0.2μ-203μ	1.89±0.44	3.47±1.47	3.00±0.20	8.12±2.68	4.09±0.06
	1.0μ-203μ	1.7	2.39	2.1	7.5	0.4

* The particulate adenylate of size fractions 0.2μ to 1.0μ and 0.2μ to 203μ were estimated by measuring 1.0μ and 203μ filterable adenylate, respectively, then subtracting the average adenylate of the 0.2μ (soluble) fraction.

Table 2. Bacterioplankton and phytoplankton standing stocks at stations A2 and A0, 1978

	Stations					
	A0			A2		
Sampling date	B[1] 10^9 cells·liter^{-1}	B[2] μgC·liter^{-1}	P[3] μgC·liter^{-1}	B[1] 10^9 cells·liter^{-1}	B[2] μgC·liter^{-1}	P[3] μgC·liter^{-1}
June 7	0.75 ± 0.08	6.0	87.8	1.88 ± 0.14	15	309
August 2	0.64 ± 0.7	5.0	70.4	1.79 ± 1.5	14	727
October 19[4]	-	-	-	3.63[4]	29[4]	340
December 6	0.7 ± 0.13	5.5	377	0.47 ± 0.14	3.8	172.5

Method of calculation of data:

[1] Bacterioplankton number of AODC ± one SD

[2] Bacterioplankton biomass (see part IIIA of this report).

[3] Phytoplankton biomass (see part IIIA, this report).

[4] Average of October 4 and November 6 values.

Table 3. Summary of the uptake velocities, turnover rates and times, and kinetic constants K_T and V_{max} at stations A2 and A0, 1978, both from simple and M-M kinetics.

Sampling date 1978	Station	S_n nmol $TA \cdot L^{-1}$	V_{max} nmol $TA \cdot L^{-1}$	V_{max} nmol $TA \cdot 10^9$ $cell^{-1} \cdot h^{-1}$	K_T nmol $TA \cdot L^{-1}$	$T_t{}^a$ h	$T_r{}^b$ $10^{-6} \cdot h^{-1}$ $cell^{-1} \cdot L^{-1}$	$T_t{}^c$ h	$T_r{}^d$ $10^{-6} h^{-1}$ $cell^{-1} \cdot L^{-1}$	$v_p{}^e$ nmol $TA \cdot L^{-1} \cdot h^{-1}$	v_{ps} nmol·TA $cell^{-1} \cdot h^{-1}$	$v_n{}^f$ nmol·TA $L^{-1} \cdot h^{-1}$	v_{ns} nmol $TA \cdot 10^9$ $cell^{-1} \cdot h^{-1}$
6-7	A0	1.74	-	-	-	-	-	42.5	31.4	0.20	0.26	-	-
6-7	A2	3.97	3.7	1.97	65.4	17.7	30.0	9.8	-	-	-	-	-
8-2	A0	1.41	-	-	-	-	-	258.4	6.1	0.03	0.05	-	-
8-2	A2	11.96	1.75	0.98	11.9	6.8	82.1	13.2	61.4	0.87	0.49	0.51	0.29
10-19	A2	5.70[g]	1.06	0.29	27.8	26.1	10.5	-	-	-	-	0.18	0.05
12-6	A0	1.19	0.35	0.50	41.8	120.8	11.8	82.0	17.4	0.10	0.13	0.009	10.014
12-6	A2	1.53	0.93	1.98	105.4	112.8	18.9	39.8	53.4	0.20	0.43	0.013	0.025

Method of calculation:

a. ordinate intercept on Woolf plot

b. turnover rate; inverse of T_t in a

c. slope of simple kinetic curve divided into TA concentration

d. turnover rate; inverse of T_t in a

e. potential uptake rate; derived from simple kinetics

f. uptake rate at material TA concentration; derived from M-M kinetics

g. mean of dissolved TA measured 10-4-78 and 11-6-78

- no data

All other determinations are as described in methods.

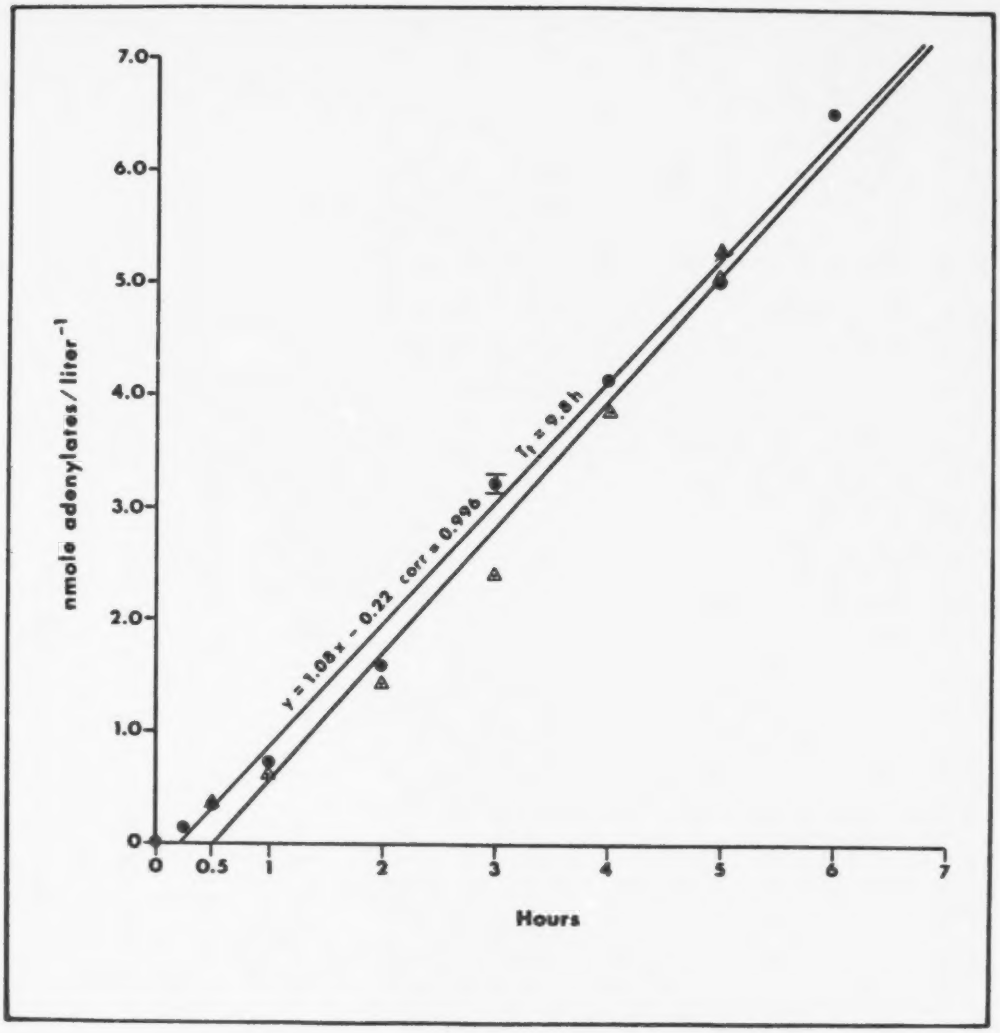


FIGURE 1. UPTAKE (●) AND INCORPORATION (▲) OF ^{3}H-AMP AT STATION A2, JUNE 7, 1978.

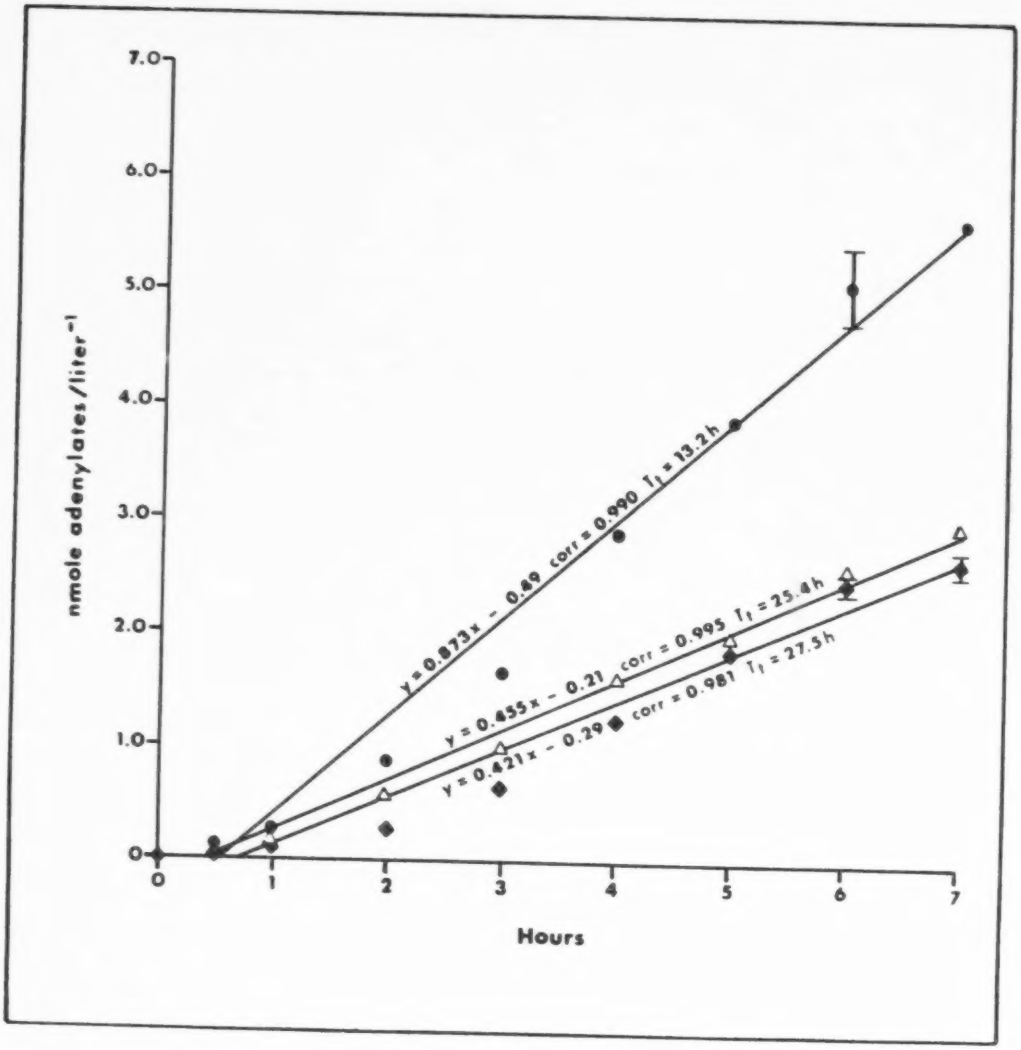


FIGURE 2. UPTAKE OF ^{3}H-AMP AT STATION A2, AUGUST 2, 1978 INTO 3 SIZE CLASSES: TOTAL (●, >0.2 µM), >1.0 µM (◆) AND >0.2 µM, <1.0 µM (Δ).

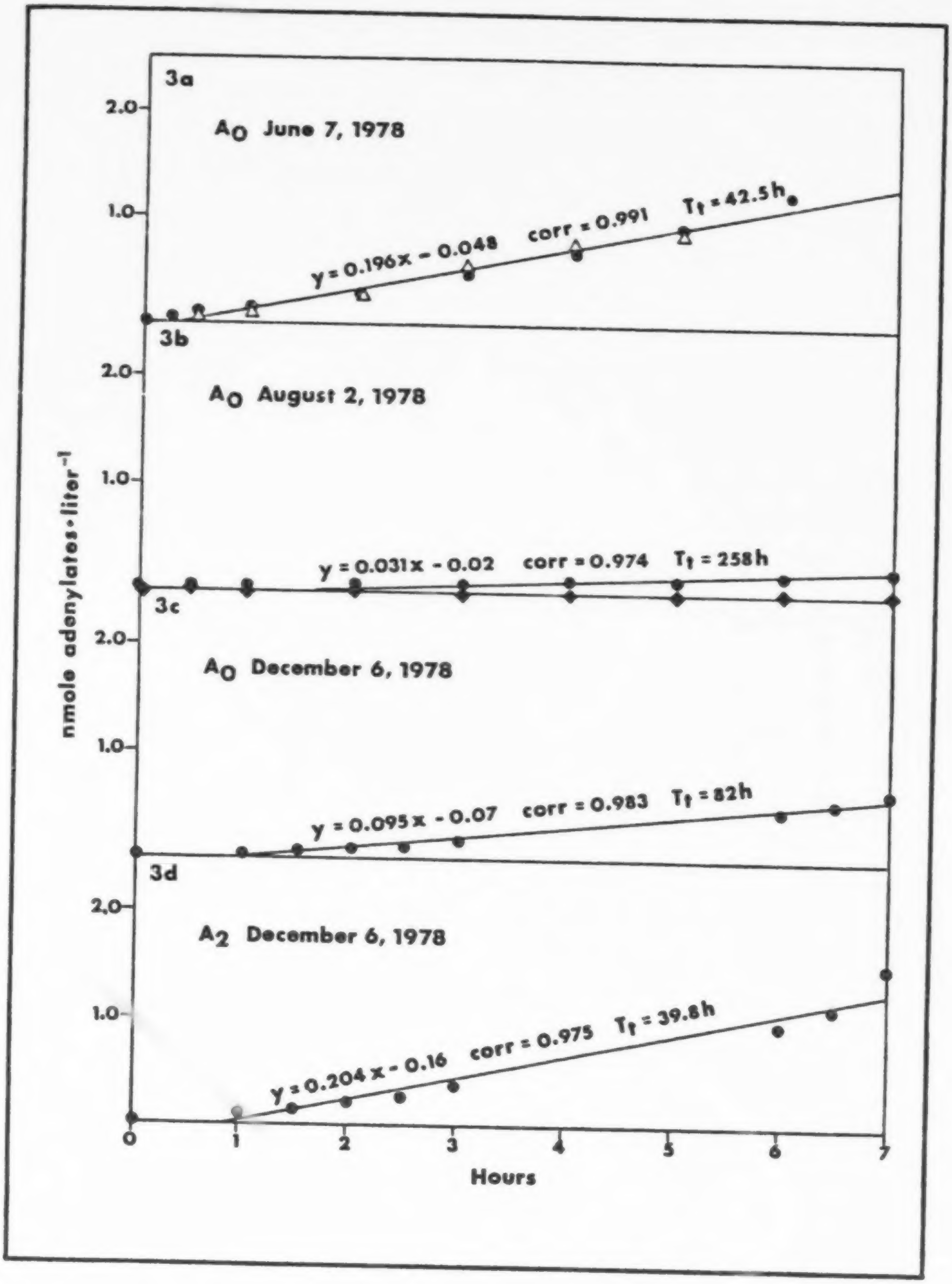


FIGURE 3a. UPTAKE (●) AND INCORPORATION (Δ) OF ^{3}H-AMP AT STATION A0, JUNE 7, 1978.

3b. UPTAKE OF ^{3}H-AMP AT STATION A2, AUGUST 2, 1978 INTO 3 SIZE CLASSES: TOTAL (●, >0.2 μM), >1.0 μM (◆) AND >0.2 μM, <1.0 μM (Δ).

3c. UPTAKE OF ^{3}H-AMP AT STATION A0, DECEMBER 6, 1978.

3d. UPTAKE OF ^{3}H-AMP AT STATION A2, DECEMBER 6, 1978.

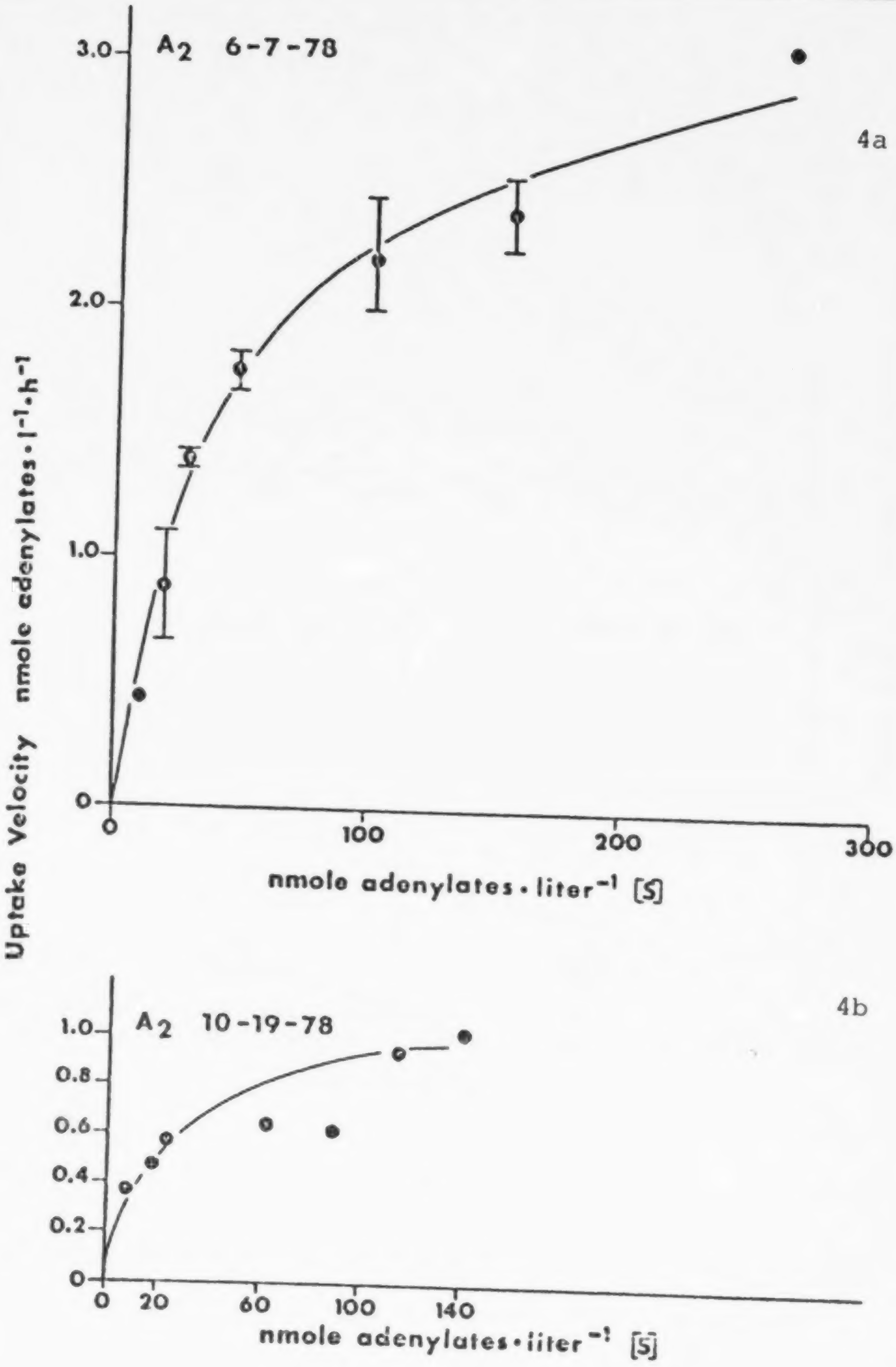


FIGURE 4a. M-M KINETICS FOR UPTAKE OF ^{3}H-AMP AT STATION A2, JUNE 7, 1978.
4b. M-M KINETICS FOR UPTAKE OF ^{3}H-AMP AT STATION A2, OCTOBER 19, 1978.

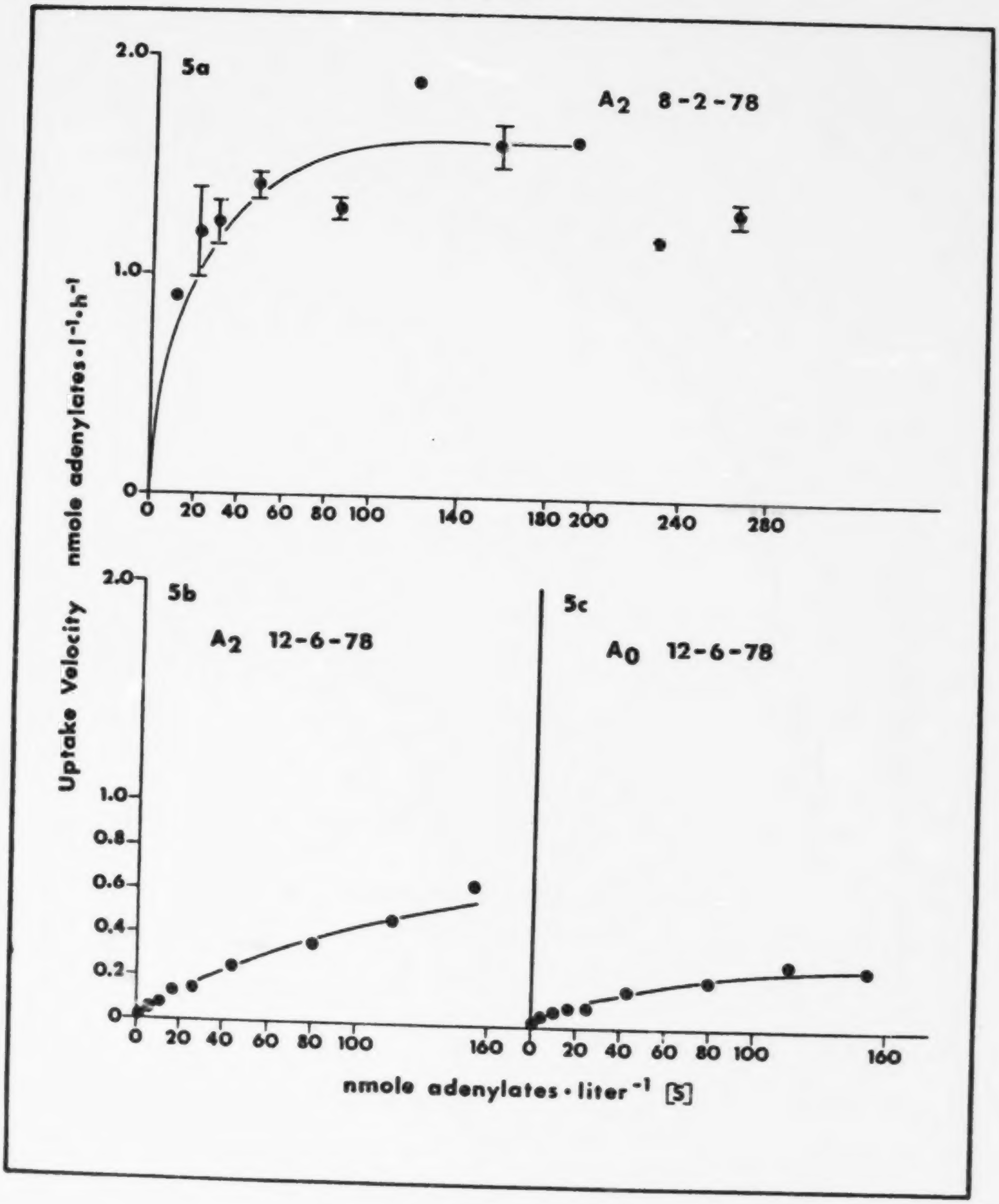


FIGURE 5a. M-M KINETICS FOR UPTAKE OF ^{3}H-AMP AT STATION A2, AUGUST 2, 1978.

5b. M-M KINETICS FOR UPTAKE OF ^{3}H-AMP AT STATION A2, DECEMBER 6, 1978.

5c. M-M KINETICS FOR UPTAKE OF ^{3}H-AMP AT STATION A0, DECEMBER 6, 1978.

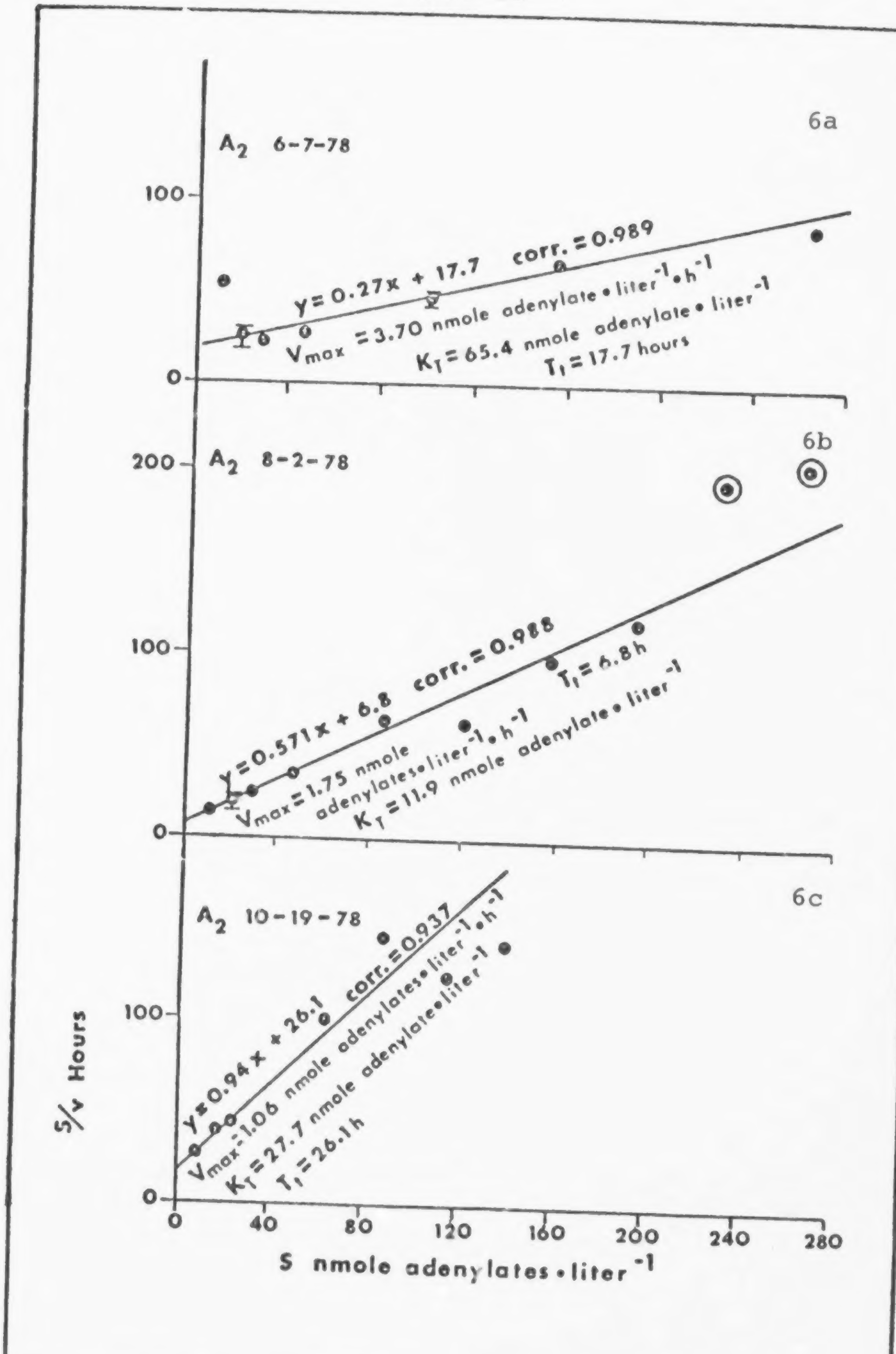


FIGURE 6a. WOOLF TRANSFORMATION (WTD) OF M-M KINETICS FOR UPTAKE OF ^{3}H-AMP AT STATION A2, JUNE 7, 1978.
6b. WOOLF TRANSFORMATION (WTD) OF M-M KINETICS FOR UPTAKE OF ^{3}H-AMP AT STATION A2, AUGUST 2, 1978.
6c. WOOLF TRANSFORMATION (WTD) OF M-M KINETICS FOR UPTAKE OF ^{3}H-AMP AT STATION A2, OCTOBER 19, 1978.

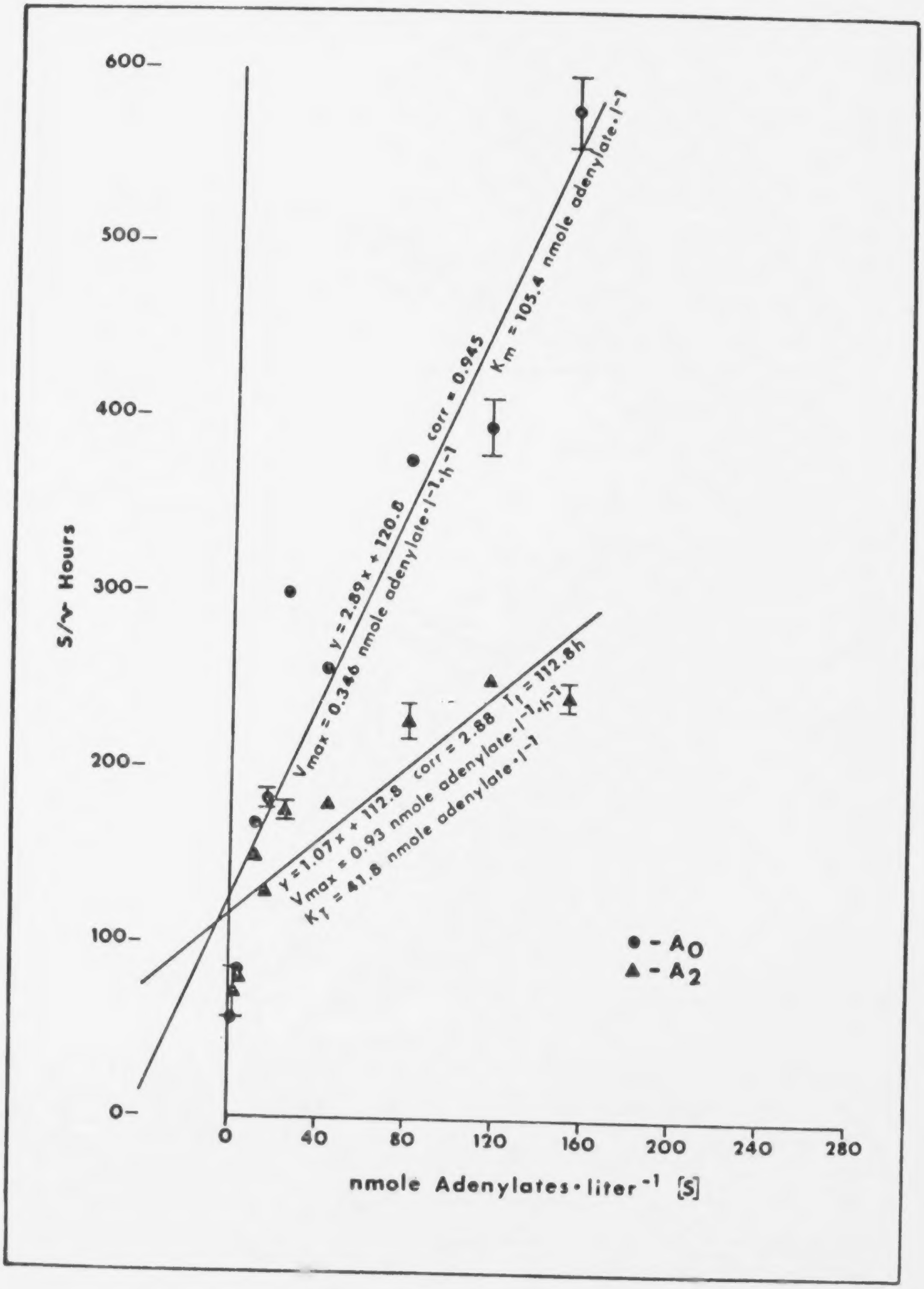


FIGURE 7. WOOLF TRANSFORMATIONS OF M-M KINETICS FOR UPTAKE OF ^{3}H-AMP AT STATIONS A0 AND A2, DECEMBER 6, 1978.

INTERACTIONS OF PHYSICAL AND BIOLOGICAL PARAMETERS

INTRODUCTION

The need for integration and evaluation of large amounts of data has increasingly required investigators to resort to statistical analytical techniques. Biological systems are generally more variable and less predictable than physical or chemical systems; furthermore, the physico-chemical factors in the environment strongly affect biological systems, controlling such things as reproductive periods, food chain sequences and distribution patterns. Attempts to identify and quantify the interactions are still dependent upon the input of biological expertise from a variety of fields. However, analytical computer methods provide the means for integrating large amounts of data for multiple parameters and for identifying which parameters have exerted the most influence on the ecoysstem at a particular time.

METHODS

Smith (1976) developed methods for ecological analysis and the use of weighted discriminant techniques, some of which were used in the first ecological study of the entire Los Angeles-Long Beach Harbors in 1973-1974 (AHF, 1976).

In the following pages hierarchical classification was used to study patterns of the biological data. Groups of biologically similar sampling sites (stations) were defined and the groups developed from the biological composition of the sites were then compared with the patterns of measured environmental parameters. From this, hypotheses concerning the relationships between the biota and the environment were suggested.

Flexible Sorting (B=.25) Strategy (Lance and Williams, 1967) and the Bray-Curtis Distance Index (Bray and Curtis, 1957; Clifford and Stephenson, 1975) were used to classify sampling sites.

The relationships between the species and the station groups defined by classification (dendrograms) were examined in two-way coincidence tables (TWT) (Kikkawa, 1968; Clifford and Stephenson, 1975). The numbers in the body of the table were transformed and standardized, and converted to symbols of species maxima as follows:

*	> .75 to 1
+	> .5 to .75
-	> .25 to .50
.	> 0 to .25
blank	0

To test for complex biotic-environmental relationships, the groups were examined by weighted discriminant analysis (Smith, 1978). Because of the technical nature of these analyses, Smith's (1978) paper is appended herein as section VIB.

Because taxonomic studies deal with only the most common identifiable species under some circumstances, and identification of rare and little known species under others, the data analyzed in the following sections were restricted so that comparisons between seasons and years could be made in a uniform manner. Thus the zooplankton analyses were restricted to copepod and cladoceran species (by far the most numerous in species and populations) and the benthic analyses were restricted to species of polychaete worms and molluscs.

Circulation in the outer Los Angeles Harbor is dominated by a large gyre, which appears to rotate much of the time in a clockwise fashion on the surface, and probably in a counterclockwise manner at depth (Robinson and Porath, 1974). The patterns tend to persist through tidal cycles, although they have been observed to break up during shifts from the prevailing southwest winds to high so-called Santa Ana Winds from the east. The gyres have been reproduced in the U.S. Army Engineers physical model of Los Angeles-Long Beach Harbors, in Vicksburg, Mississippi. Figures 1 and 2 illustrate representative conditions on incoming and outgoing tides, respectively (from McAnally, 1975).

Circulation patterns and flushing rates govern the distribution and assimilation of wastes and nutrients in the harbor. They also affect the sorting and deposition of variously sized sediment particles, which in turn affect the habitats of benthic organisms. Circulation serves to distribute the planktonic larvae (meroplankton or temporary plankton) of indigenous organisms, and tidal exchange brings both larvae and adult zooplankton into the harbor. The distribution patterns developed in the station groupings for the following sections at times show evidence for the influence of the main gyre and for a transitory counterclockwise gyre in the western part of the outer harbor.

WEIGHTED DISCRIMINANT ANALYSIS OF ZOOPLANKTON

Zooplankton data, discussed in section IID, were examined on a quarterly basis by discriminant analysis techniques for the two-year period beginning in December 1976. At that time, DAF-treated cannery wastes and primary-treated TITP sewage were entering the harbor. The results of each period are discussed in the following pages and illustrated for each seasonal quarter.

RESULTS

December, 1976.

Stations for this period are well separated into an outer harbor-outside harbor group, a shallower, nearshore group, and the outfall area (A7) (Figures 3 and 4). The separations into groups are made on the basis of species distributions and numbers shown in the Two Way Table (TWT, Figure 5).

The weighted means of the physical and biological (phytoplankton) parameters used are presented in Table 1. Table 2 shows the coefficients of separate determination, in which higher values provide indication of the important variables in separating the groups. Generally coefficients of 10 or above are considered important; the percent of information in each axis is indicated on Table 2, and only coefficients on axes with content of 1% or above are considered herein.

According to the coefficients, temperature, pH and chlorophyll *a* were the important factors of the parameters measured. This does not discount the real possibility that, in some instances, parameters not measured exert significant influence and the station groupings will not be as clearcut as they were in December 1976. Group 3 sites had the highest weighted mean dissolved oxygen (DO), pH, primary productivity and assimilation ratio, and the lowest chlorophyll *a* and salinity. The outfall (Group 2) had the highest temperature and salinity, lowest DO and pH, and lowest productivity and assimilation ratio. Group 1 sites were intermediate in almost all parameters and were also intermediate in space. The important vectors and the station groups are located on the axes in Figure 6. The data on nutrients such as ammonia and nitrate were not included because these are represented in the phytoplankton crop. The harbor has not been considered nutrient limited in the past.

March 1977.

The explosion and Bunker C spill from the tanker *Sansinena* occurred two weeks after the December field sampling. Analysis of the immediate area (A9, A10) influenced by that event showed that oil and grease levels in the water column were important to the benthic and zooplankton populations in the western harbor where 22 sampling stations were established in December 1976 following the blast (Soule and Oguri, 1978). Oil and grease measurements were not a part of the TITP study, but the March pattern suggests a connection, probably tidally induced, for Group 2 stations (Figures 7 and 8). The TWT (Figure 9) shows a considerable reduction in species or populations at Group 2 stations over the December TWT (Figure 3). On the other hand, station A7 showed an increase, allying it with A 11 as Group 3.

Table 3 shows the weighted variable means for each group, and Table 4 gives the coefficients of separate determination. Salinity, light transmittance, pH, productivity and chlorophyll *a* are the important variables, with DO parallel to pH but to a lesser extent. The vectors are plotted in Figure 10 for the station groups.

Group 2 stations had the lowest mean temperature, productivity and chlorophyll *a*, and the highest salinity, DO, pH, transparency and assimilation ratio. The high pH and DO do not suggest inhibition, and in fact the phytoplankton may have been stimulated. The zooplankton groups differ markedly from the benthic groupings for the same period (section IVB).

June 1977.

Secondary waste treatment of TITP effluent began in April 1977 and may or may not have affected harbor station groupings, but the populations appear to have been impacted. Certainly the patterns show considerable overlap for Groups 1 and 2 (Figures 11, 12). The TWT (Figure 13) shows that there were less than half as many species present in June 1977 as were present in December 1976 and only Group 3 (A1 outside the harbor) has good populations. There may be normal drops in species in the summer, perhaps due to predation.

In this period phytoplankton factors dominated the variables, with only temperature and pH having minor roles, according to the coefficients of separate determination. Group 3 was separated by having the highest salinity, pH and transparency, and the lowest productivity and chlorophyll *a*. Group 4 (station A4), which rarely stands alone, was isolated in both zooplankton and benthic analyses. For zooplankton it had the highest temperature, productivity and chlorophyll *a*, and the lowest pH, transparency and assimilation ratio. A bloom may have been just getting underway (see section (IIC). Groups 1 and 2 were intermediate in most measures, except for temperature, where group 1 was lowest, and assimilation ratio, where group 2 was highest. Figure 14 shows the important vectors and the station groups.

September 1977.

By September the zooplankton seemed to have mostly recovered from the disturbance that had caused the low numbers of species and organisms, except for the outfalls area, which had lost most of its fauna. This suggests continuing impact locally from effluent changes. This contrasts with the benthic fauna, discussed in the next section, wherein the station groupings continued to indicate more extensive abnormal separation.

The plankton station groups (Figures 15, 16) were more or less arrayed concentrically from the outfall. However, the TWT (Figure 17) shows that group 1 stations were low in numbers. This included station A10, which may have been affected by residual oil, deposited after the *Sansinena* incident, and tends to leach in warm weather. Groups 3 and 4 (the outermost harbor and the sea buoy) were much richer.

The weighted means of variables measured are shown in Table 7 and the coefficients in Table 8. Interestingly, all variables were significant on one or more axes. These are plotted in Figure 18. The outfall (Group 2) was highest in weighted means for temperature, productivity and chlorophyll *a*, and lowest in salinity, DO, pH and assimilation ratio. Group 1, adjacent to the outfall station group, was second highest in temperature, salinity, productivity and chlorophyll *a*, and next lowest in DO, pH and assimilation ratio. Low assimilation ratios in groups 1 and 2 suggest stress in the areas. The sea buoy (group 4) was highest in DO, pH and assimilation ratio and lowest in productivity and chlorophyll *a*. Group 3 stations were colder than the sea station. The fluctuations in stabilizing secondary TITP effluent prior to diversion of cannery wastes undoubtedly influenced the zooplankton to some extent and the sessile benthic populations perhaps to a greater extent. One cannery effluent was diverted to TITP in October 1977 and the second by January 1978. Were it not for the high coefficients for dissolved oxygen and assimilation ratios, the pattern on the map might be considered as normal zonation.

December 1977.

The zooplankton patterns in December began to show an increase in numbers of species and individuals, except for a few anomalies (Figures 19, 20). Species numbers were not as high as in December 1976, however. It is apparently a normal winter pattern for the sea station to join outermost harbor stations, as is true in group 1. Group 2, overlapping, is distinct in having fewer species but with higher numbers (TWT, Figure 21), whereas Group 3, station B8, appears to be abnormally low in species. It was lowest in temperature and in chlorophyll *a*, but highest in assimilation ratio and pH. On the other hand, the outfalls area has merged with adjacent stations (group 4) with increased species. Conditions in

December might have represented an ideal situation, with lower levels of cannery waste in combination with TITP secondary waste for the immediate effluent zone but the station B8 area seems to have suffered a retreat.

The weighted means (Table 9) showed a mixed pattern for the groups, with group 1 having the highest means for salinity, productivity and chlorophyll *a* and lowest for DO. However, the coefficients (Table 10) showed that only temperature and pH were significant physical variables, and the phytoplankton variables were of greater importance. Group 4 sites had the highest weighted mean temperature and lowest pH and assimilation ratios. Thus a mixed pattern is achieved, based on physical and biological variables. The vectors are plotted in Figure 11.

April 1978.

The April patterns for zooplankton showed some apparent impact in the nearshore area, with the innermost station groupings mixed (Figures 23, 24). The TWT (Figure 25) shows a reduction in species distribution and in numbers as compared with December 1977, and the reverse might have been expected when populations usually increase.

Weighted means and coefficients are given in Tables 11 and 12. All of the variables were important and separations were made on four axes. Of the single station isolates, group 5 (station B9) had the highest weighted mean temperature, DO and pH and the lowest transparency, productivity and chlorophyll *a* as well as the second lowest assimilation ratio. It had large populations of common zooplankton species, which may have grazed the phytoplankton. Group 3 had the lowest mean temperatures and highest transparency and productivity. Group 4 overlapped, but had the lowest DO and pH and second lowest temperature. Note that the waters were cooler closer to shore. Group 1 had the highest assimilation ratio and lowest salinity, and Group 2 had the lowest assimilation ratio and highest salinity. The high dissolved oxygen and high coefficients for phytoplankton suggest that a small, patchy bloom may have been in progress. The vectors and station groups are shown in Figure 26. The benthic patterns were also highly mixed in April. It seems probable that the unusually heavy rains in January, February and March (about 27 inches) were responsible and may have led to the massive upset in the treatment plant in the summer. The unstable patterns in Figure 23 may have been due to variability in release of nutrients and in the control measures instituted by TITP.

July 1978.

By midsummer the stations were again divided into 5 groups (Figures 27, 28), but the separations were somewhat different. The TWT (Figure 29) shows that species diversity was better than in the summer of 1977, although the summer appears to have fewer species in the harbor when it is warmer than are there in the winter. As was the case in April, station B9 stood alone, this time as group 3; also the sea buoy station was separated, as it often is in summer, and the outfall was separated, as it is when nutrient levels are higher.

Group 2 (the sea buoy) had the lowest temperature and DO (Table 13) but was intermediate on all other parameters. Group 3 had the highest weighted mean temperature and transparency, and the lowest salinity, pH, productivity, chlorophyll *a* and assimilation ratio. It would appear that water might have pooled at B9 during the summer, where tidal water coming in from the east meets the gyre. Group 5, the outfall, had the highest DO, pH, productivity, chlorophyll *a* and assimilation ratio, a very unusual circumstance. Groups 1 and 4 overlapped spatially and had intermediate values in the various parameters. All parameters except light transmittance were important according to the coefficients (Table 14). Vectors are plotted in Figure 30.

September 1978.

The station pattern in September 1978 is very confused (Figures 31, 32) and is probably indicative of the fact that the high nutrient levels had again been terminated and secondary treatment at TITP was brought back on line. The "yo-yo" effects of waste treatment over the two-year period have made populations transitory at best. In September, the species list (TWT, Figure 33) was better than it was the previous year, but only the stations on the periphery (groups 1, 2 and 5) appeared to have good populations. The split between groups 3 and 4, with the outfall included in group 4, is different from previous patterns.

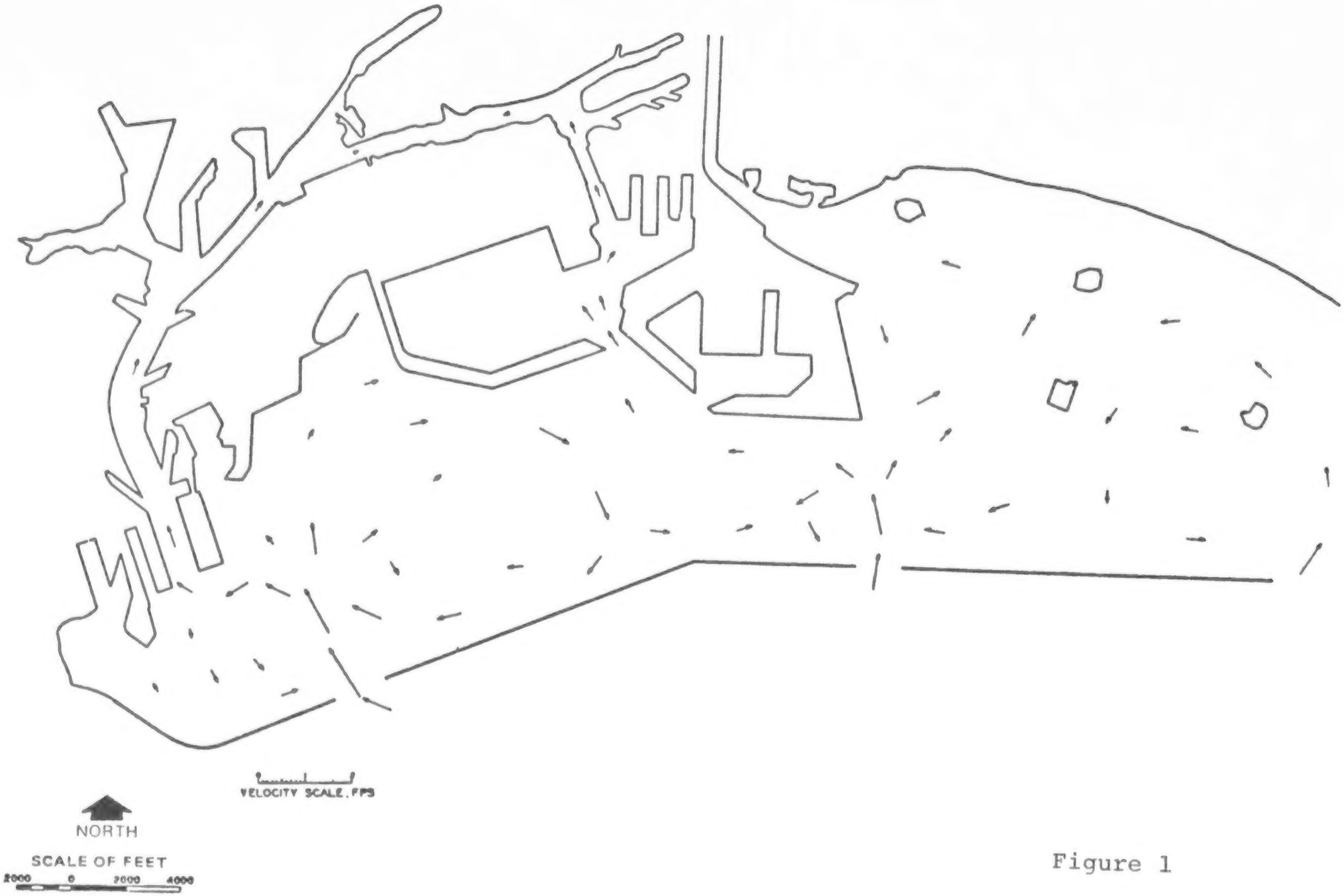
Group 5 (B9 again was separated) was very different in having much higher weighted mean productivity and chlorophyll than had been seen for some time (Table 15). It also had the highest salinity, DO, pH and light transmittance but the lowest assimilation ratio and temperature. Group 1 was second lowest in temperature, salinity, and all three phytoplankton measures. Group 2 (A1) had the lowest chlorophyll *a*, salinity, DO, pH and transparency, an interesting reversal of patterns. There had been about 0.5 in of rain the day before the sampling so that salinities were low at the surface.

Groups 3 and 4 would probably have merged, except that group 3 had the lowest productivity and highest assimilation rates; and in all other measures the two groups were at intermediate levels. The coefficients (Table 16) indicated that all parameters measured except temperature and salinity were important. This is also an unusual occurrence, but the lack of variation in the two parameters throughout the stations would explain that.

The vectors are plotted in Figure 34 for the station groups. In this case group 5 is so different that the others are arrayed on the opposite side, but good separation is still accorded the groups.

LITERATURE CITED See Section VIA.

METHODS SECTION, DISCRIMINANT ANALYSIS See Section VIB.



Source: McAnally, 1975

Figure 1

SURFACE CURRENT PATTERNS
Base Test, Spring Tide Hour 6

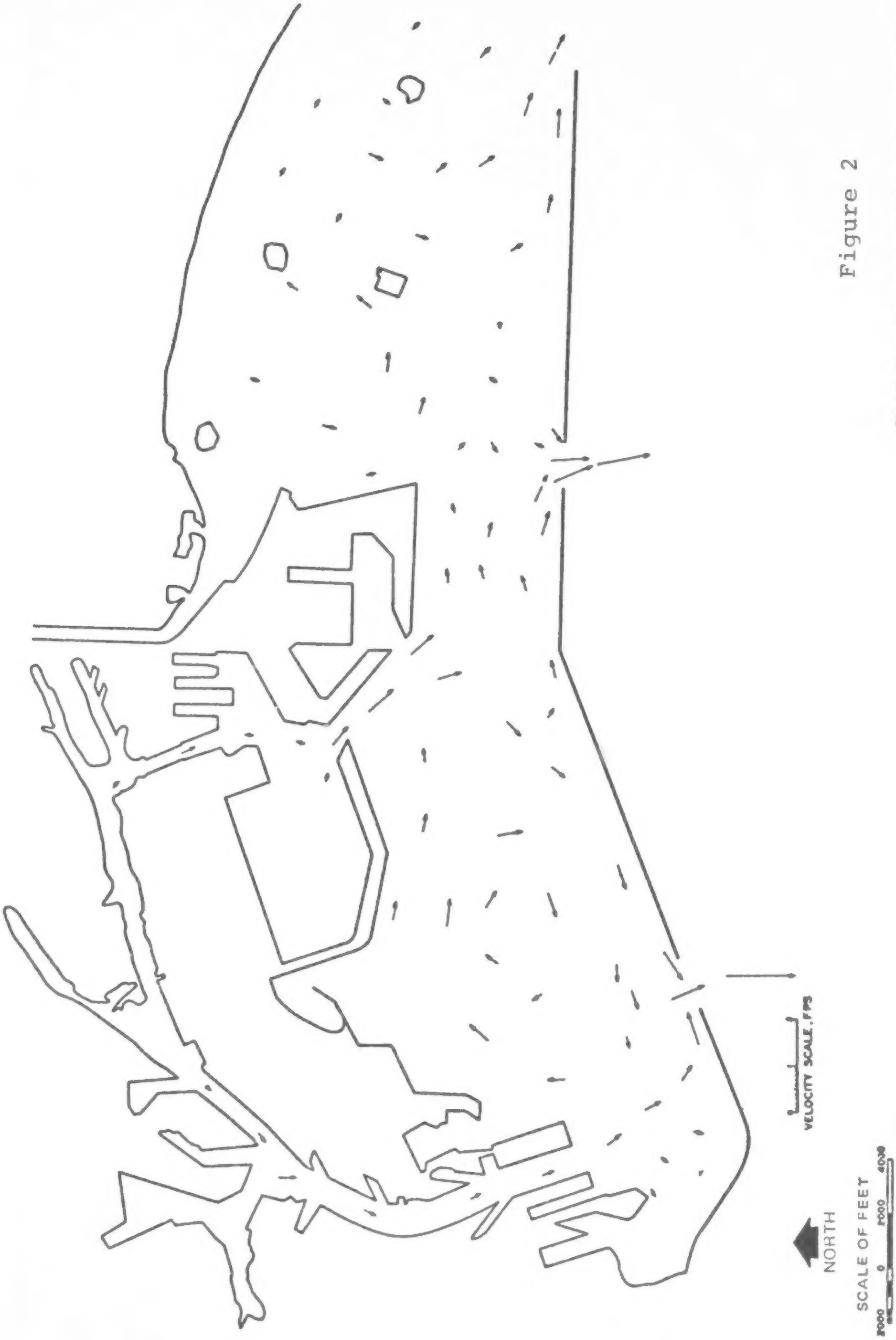


Figure 2

SURFACE CURRENT PATTERNS
Base Test, Spring Tide Hour 13

Source: McAnally, 1975.

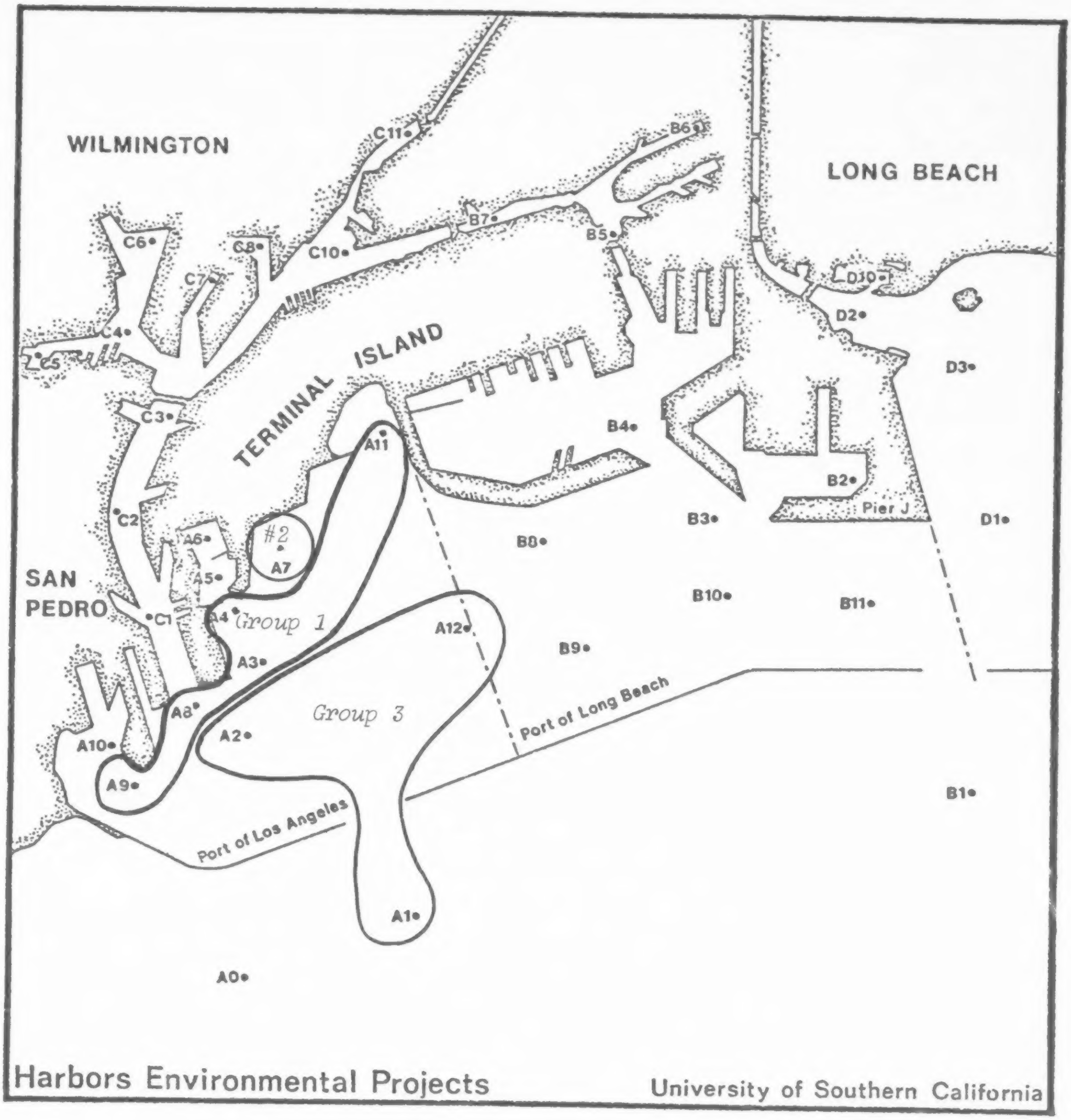


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FIGURE 3. ZOOPLANKTON STATION GROUPS, DECEMBER 1976.
GROUP 1 - A3, A4, A8, A9, A11   GROUP 3 - A1, A2, A12
GROUP 2 - A7

FIGURE 4.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** DECEMBER, 1976

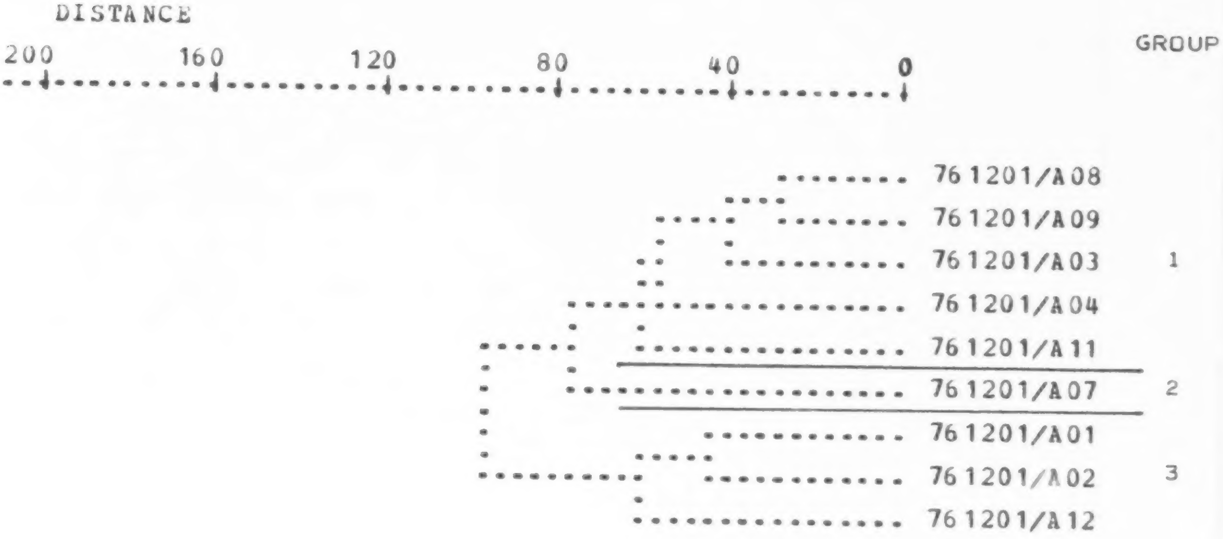


FIGURE 5.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** DECEMBER, 1976

*	> .75 TO 1
+	> .50 TO .75
-	> .25 TO .50
.	> .00 TO .25
BLANK	.00

	761201/A08	761201/A09	761201/A03	761201/A04	761201/A11	761201/A07	761201/A01	761201/A02	761201/A12
STATION GROUP	1					2	3		
CLYTEMNESTRA ROSTRATA									*
ONCAEA MEDITERRANEA									*
ONCAEIDAE ONCAEA									*
PSEUDOCALANIDAE CLAUSOCALANUS									*
CLAUSOCALANUS FURCATUS							*	+	+
OITHONA PLUMIFERA		-					*	+	-
CORYCAEUS AMAZONICUS	.						*	+	*
MECYNOCERA CLAUSI	.						*	+	
EVADNE SPINIFERA		.	-	.			*	.	-
PENILIA AVIROSTRIS	.	-	+	.	.		*	+	-
CALANUS HELGOLANDICUS							*		-
CALOCALANUS STYLIREMIS	-						*		+
CLAUSOCALANUS MASTIGOPHORUS							*		
ACARTIA CLAUSI					*		+		
CTENOCALANUS VANUS							+	*	
TEMORA DISCAUDATA								*	
TORTANUS DISCAUDATUS			-					*	-
ACARTIA TONSA	+	+	+	-	+	.	.	*	-
PARACALANUS PARVUS	*	-	-	+	+	.	-	*	-
LABIDOCERA TRISPINOSA	+	*	-	+			+	*	.
EVADNE NORDMANNI	-	*	*		+		+	*	
CORYCAEUS ANGLICUS	+	*	-	.		-	*	-	.
OITHONA SIMILIS	+	*	-			+	*	+	-
EUTERPINA ACUTIFRONS	-	*				+			
PODON POLYPHEMOIDES	-	*	-	*	-	-			.
OITHONA OCULATA						*			

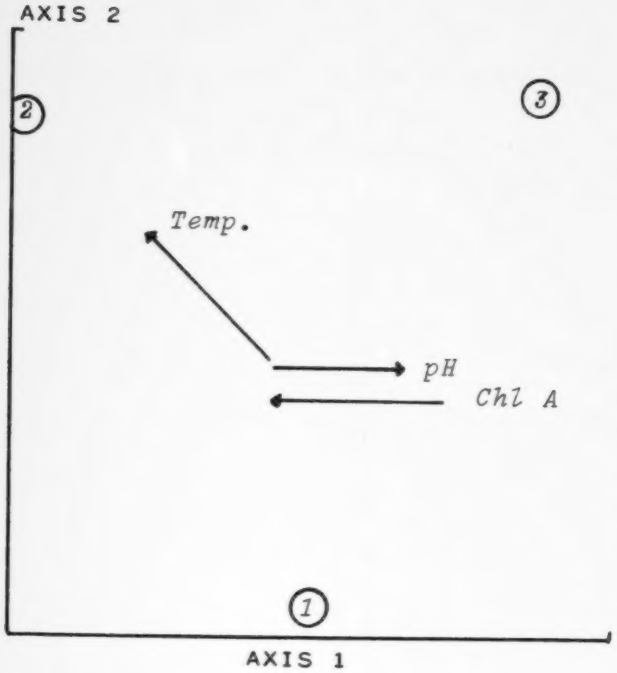


FIGURE 6. PLANKTON STATION GROUPS AND AXES, WITH VECTORS
DECEMBER 1976

TABLE 1.

```
WEIGHTED GROUP MEANS
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** DECEMBER, 1976

                    GROUPS       1           2           3

  1. TEMPERATURE             17.3326     17.4439     17.3885
  2. SALINITY                32.9399     32.9506     32.9366
  3. OXYGEN                   6.5803      6.3217      6.9872
  4. PH                       6.1379      8.1014      8.1718
  5. PRODUCTIVITY             1.7753      1.5801      1.8108
  6. CHLOROPHYLL A            1.3736      1.6919      1.2268
  7. ASSIMILATION RATIO       1.3715      1.1716      1.4476

** ONE-WAY ANOVA FOR EACH VARIABLE * DF =    2.   24
        VARIABLE                     F
  1.    TEMPERATURE                 0.06
  2.    SALINITY                    0.01
  3.    OXYGEN                      0.22
  4.    PH                          0.24
  5.    PRODUCTIVITY                0.02
  6.    CHLOROPHYLL A               0.31
  7.    ASSIMILATION RATIO          0.06
```

TABLE 2.

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS     ROOT              %        CUM %    CHI SQUARED      DF
 1   8.863E-02          83.8        83.8         1.78          8
 2   1.709E-02          16.2       100.0         0.36          6

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** DECEMBER, 1976

                          AXES     1       2

  1. TEMPERATURE                  6.5    57.2
  2. SALINITY                     3.5     0.9
  3. OXYGEN                       3.9     5.0
  4. PH                          19.1     3.9
  5. PRODUCTIVITY                 1.9     6.4
  6. CHLOROPHYLL A               60.9    23.7
  7. ASSIMILATION RATIO           4.2     3.0
```

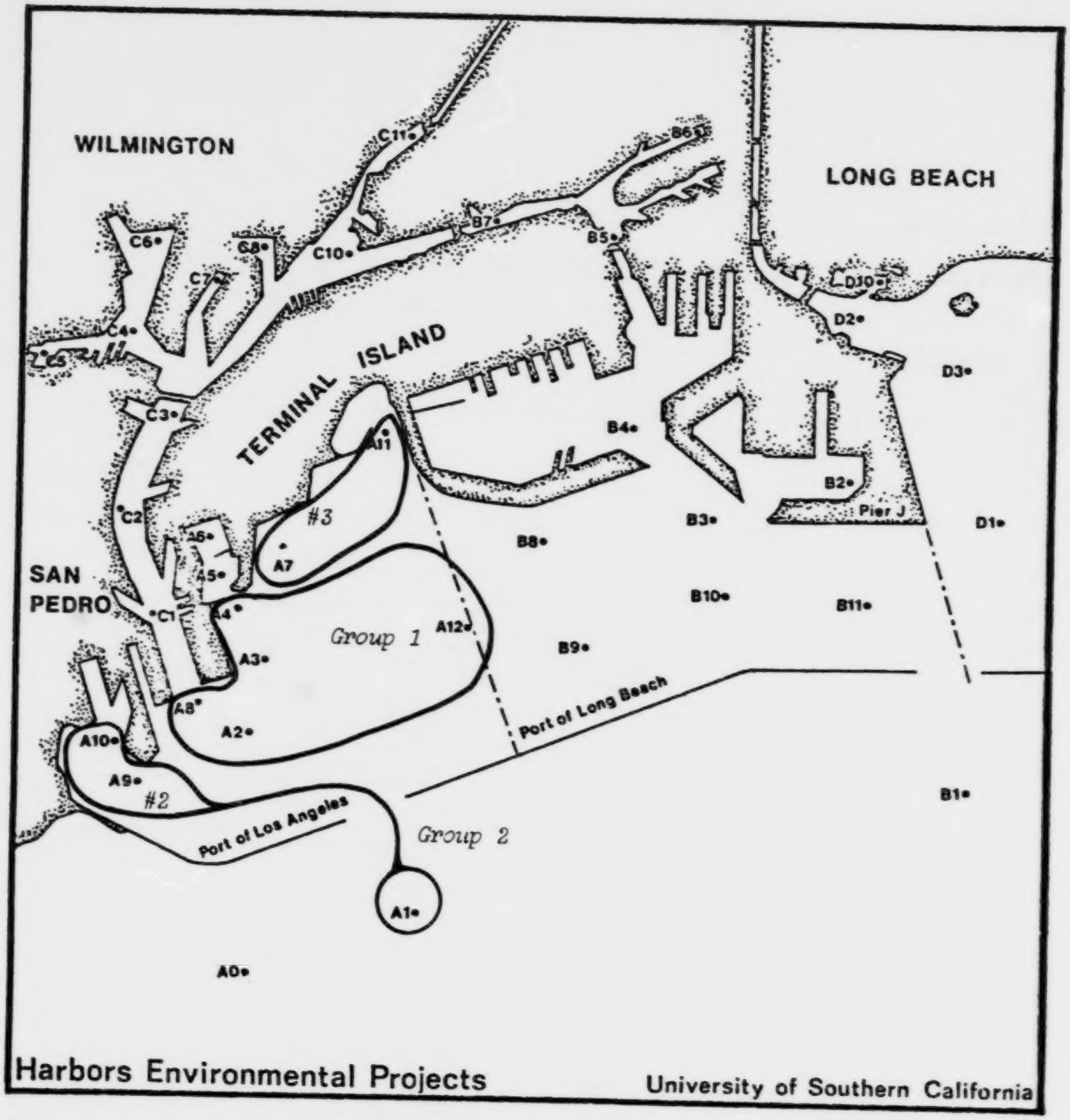


FIGURE 7. PLANKTON STATION GROUPS, MARCH 1977

GROUP 1 - A2, A3, A4, A8, A12 GROUP 3 - A7, A11
GROUP 2 - A1, A9, A10

FIGURE 8.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** MARCH, 1977

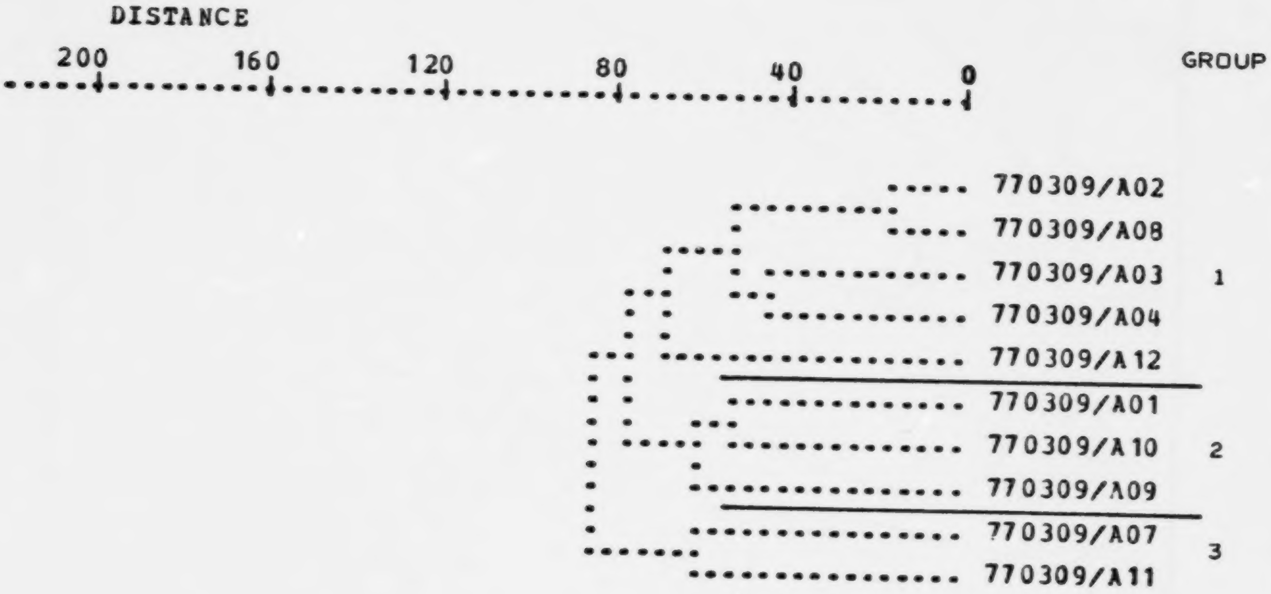


FIGURE 9.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** MARCH, 1977

*	> .75 TO 1
+	> .50 TO .75
-	> .25 TO .50
.	> .00 TO .25
BLANK	.00

STATION GROUP	1					2			3	
	770309/A02	770309/A08	770309/A03	770309/A04	770309/A12	770309/A01	770309/A10	770309/A09	770309/A07	770309/A11
OITHONA SIMILIS					*					
OITHONA SPINIROSTRIS					*					
CORYCAEUS AMAZONICUS				-	*	+	.	-		
OITHONA OCULATA					-					*
OITHONIDAE OITHONA				*			-			
ONCAEIDAE ONCAEA								*		
OITHONA PLUMIFERA			*	*				+		
RHINCALANUS NASUTUS			*	*						
CANDACIIDAE CANDACIA			*							
PENILIA AVIROSTRIS			*		*					
CORYCAEUS ANGLICUS	+	*	*	+		.		.		
EVADNE SPINIFERA	+	*	*	+	-	-		.		
EVADNE NORDMANNI	-	*	*	+	-	.	.	-	*	
PODON POLYPHEMOIDES	-	+	-	-	.	.	.	-	*	.
ACARTIA TONSA	.	-	-	.	-	.	.	.	*	*
LABIDOCERA TRISPINOSA	+	+	+		*	.	-		*	-
PARACALANUS PARVUS	*	*	+	*	+	.	-	+	-	-
MICROSETELLA NORVEGICA									*	
TEMORA DISCAUDATA								.	*	
EUTERPINA ACUTIFRONS		.		-	.				*	.
ONCAEA VENUSTA				+					*	

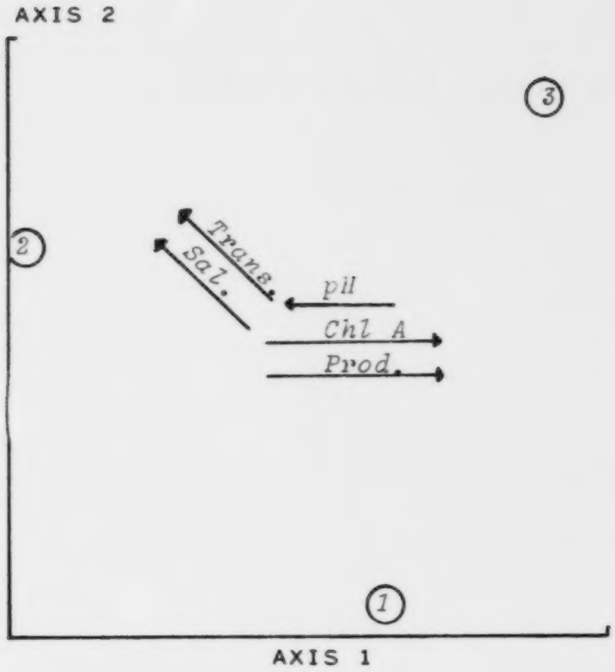


FIGURE 10. PLANKTON STATION GROUPINGS AND AXES, WITH VECTORS MARCH 1977

TABLE 3.

```
WEIGHTED GROUP MEANS
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** MARCH, 1977

                    GROUPS            1            2            3

  1. TEMPERATURE                14.4329      14.3718      14.4980
  2. SALINITY                   31.5397      31.5807      31.5482
  3. OXYGEN                      9.4756       9.5403       9.3327
  4. PH                          8.2092       8.2195       8.2026
  5. %TRANSMITTANCE             47.7434      51.9859      47.7678
  6. PRODUCTIVITY               12.8033      11.7875      13.0199
  7. CHLOROPHYLL A               5.3071       4.8048       5.5775
  8. ASSIMILATION RATIO          2.3053       2.3162       2.3093


** ONE-WAY ANOVA FOR EACH VARIABLE * DF =     2,    27
      VARIABLE                        F
  1.   TEMPERATURE                  0.06
  2.   SALINITY                     0.02
  3.   OXYGEN                       0.02
  4.   PH                           0.01
  5.   %TRANSMITTANCE               0.04
  6.   PRODUCTIVITY                 0.02
  7.   CHLOROPHYLL A                0.09
  8.   ASSIMILATION RATIO           0.00
```

TABLE 4.

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS     ROOT             %         CUM %    CHI SQUARED       DF
 1   2.256E-02          63.4        63.4         C.52           9
 2   1.303E-02          36.6       100.C         0.3C           7


COEFFICIENTS OF SEPARATE DETERMINATION (X 1CO/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** MARCH, 1977

                     AXES           1          2

    1. TEMPERATURE                 8.3        9.0
    2. SALINITY                    0.9       20.3
    3. OXYGEN                      0.1        9.4
    4. PH                         14.4        1.7
    5. %TRANSMITTANCE             10.5       17.9
    6. PRODUCTIVITY               37.8       29.8
    7. CHLOROPHYLL A              26.4        6.5
    8. ASSIMILATION RATIO          1.6        5.4
```

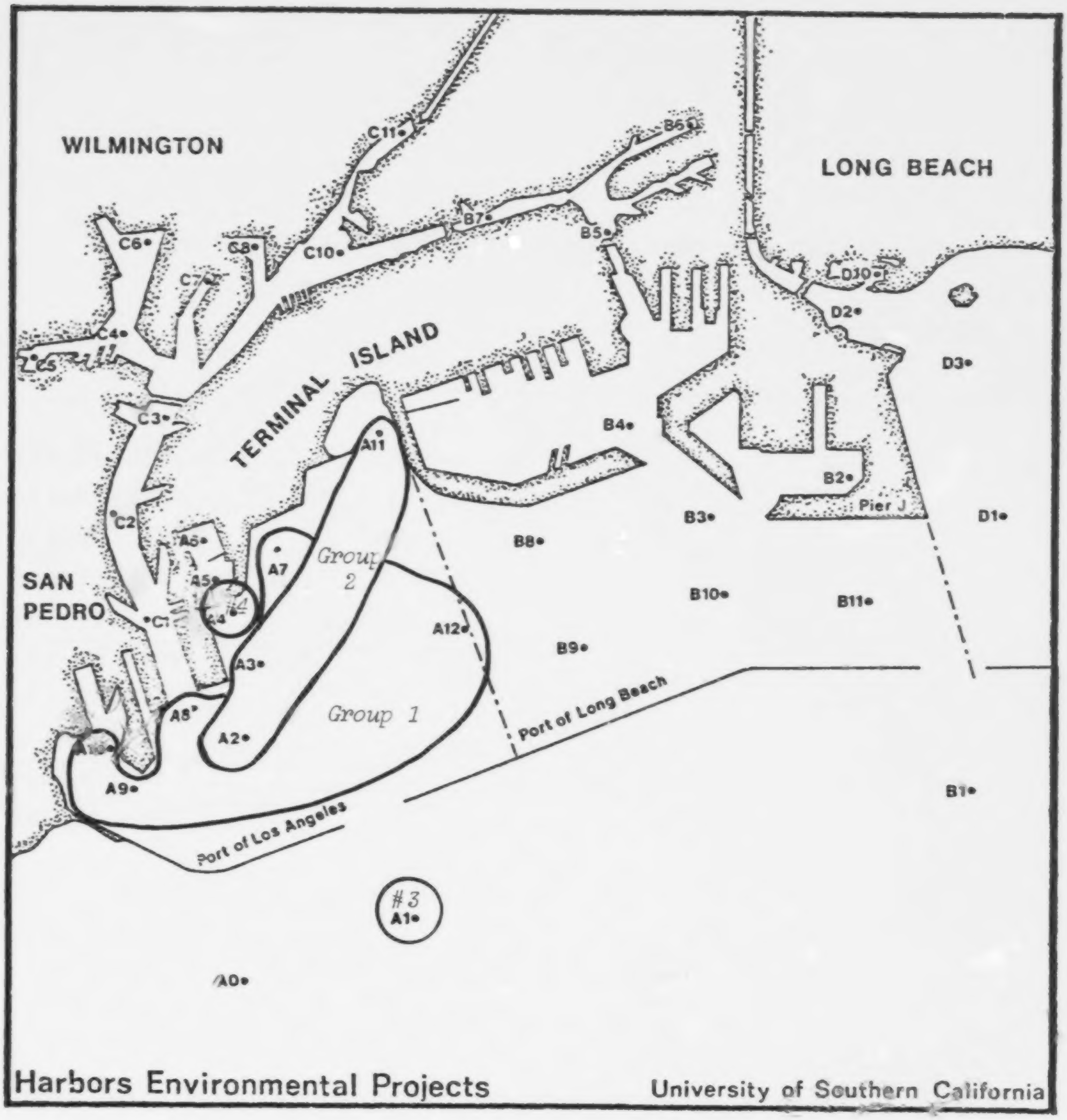


FIGURE 11. PLANKTON STATION GROUP, JUNE 1977

GROUP 1 - A7, A8, A9, A10, A12 GROUP 3 - A1
GROUP 2 - A2, A3, A11 GROUP 4 - A4

FIGURE 12.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** JUNE, 1977

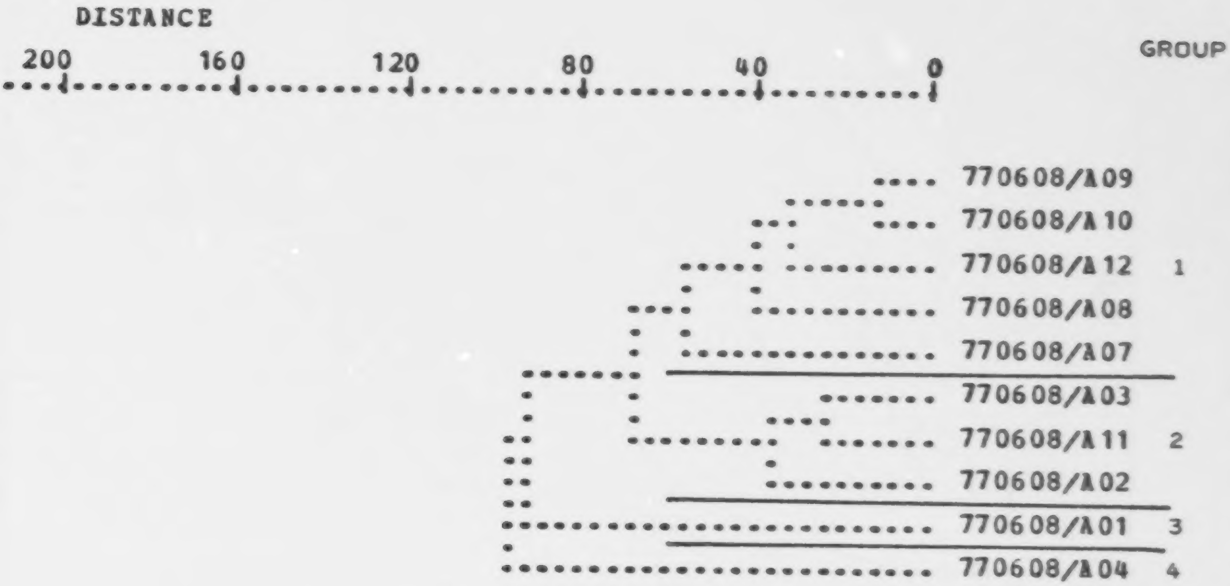
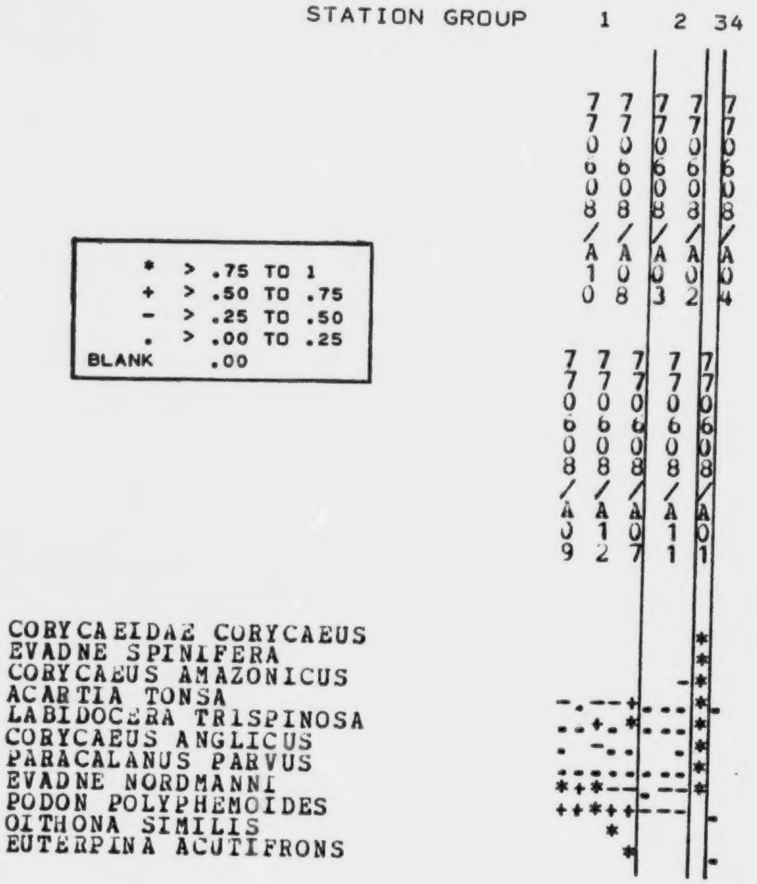


FIGURE 13.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** JUNE, 1977



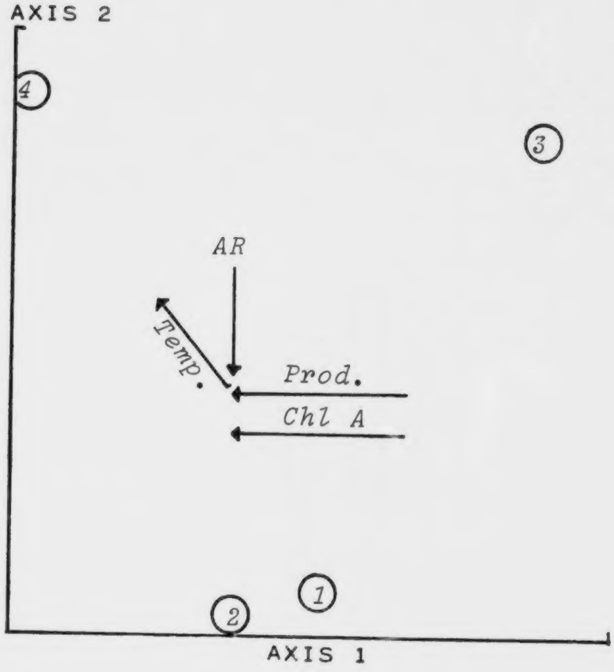


FIGURE 14. PLANKTON STATION GROUPS AND AXES, WITH VECTORS
JUNE 1977

```
TABLE  5.

WEIGHTED GROUP MEANS
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** JUNE, 1977

                  GROUPS       1          2          3          4

  1. TEMPERATURE            19.1895    19.2420    19.2481    19.3084
  2. SALINITY               33.6385    33.6359    33.6506    33.6451
  3. OXYGEN                  7.6486     7.6606     7.5555     7.5963
  4. PH                      7.9623     7.9652     8.0031     7.9438
  5. %TRANSMITTANCE         61.9045    62.0058    67.6584    54.7498
  6. PRODUCTIVITY           12.8767    13.2863    11.1094    13.3312
  7. CHLOROPHYLL A           2.0327     2.0490     1.7713     2.1573
  8. ASSIMILATION RATIC      6.8422     7.0198     6.8130     6.6267


** ONE-WAY ANOVA FOR EACH VARIABLE * DF =    3,   36
      VARIABLE                    F
  1.   TEMPERATURE               0.03
  2.   SALINITY                  0.01
  3.   OXYGEN                    0.02
  4.   PH                        0.08
  5.   %TRANSMITTANCE            0.24
  6.   PRODUCTIVITY              0.30
  7.   CHLOROPHYLL A             0.18
  8.   ASSIMILATION RATIO        0.01
```

TABLE 6.

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS    ROOT            %        CUM %     CHI SQUARED     DF
 1   1.800E-01        76.3       76.3          5.46        10
 2   5.068E-02        21.5       97.7          1.63         8
 3   5.389E-03         2.3      100.0          0.18         6


COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** JUNE, 1977

                        AXES       1       2       3

  1. TEMPERATURE                  1.7    13.9    17.2
  2. SALINITY                     0.7     1.4     0.3
  3. OXYGEN                       1.0     3.7     0.0
  4. PH                           2.5     3.7    12.0
  5. %TRANSMITTANCE              15.6     5.8     7.0
  6. PRODUCTIVITY                36.6    23.2     2.0
  7. CHLOROPHYLL A               40.1    29.5    39.2
  8. ASSIMILATION RATIO           1.8    18.8    22.4
```

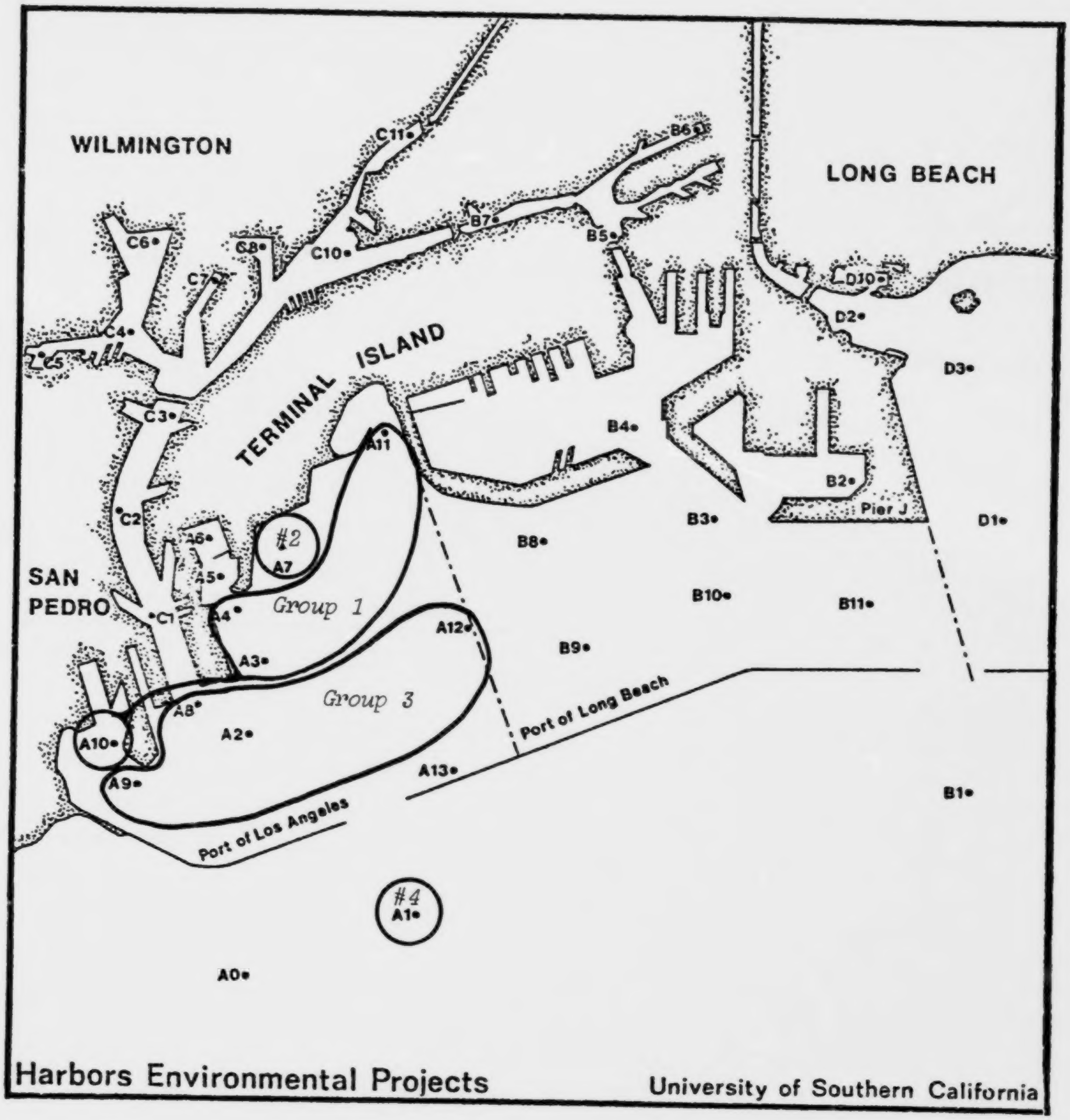


Figure 15. Plankton Station Groups, September 1977

Group 1 - A3, A4, A10, A11
Group 2 - A7
Group 3 - A2, A8, A9, A12
Group 4 - A1

FIGURE 16.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** SEPTEMBER, 1977

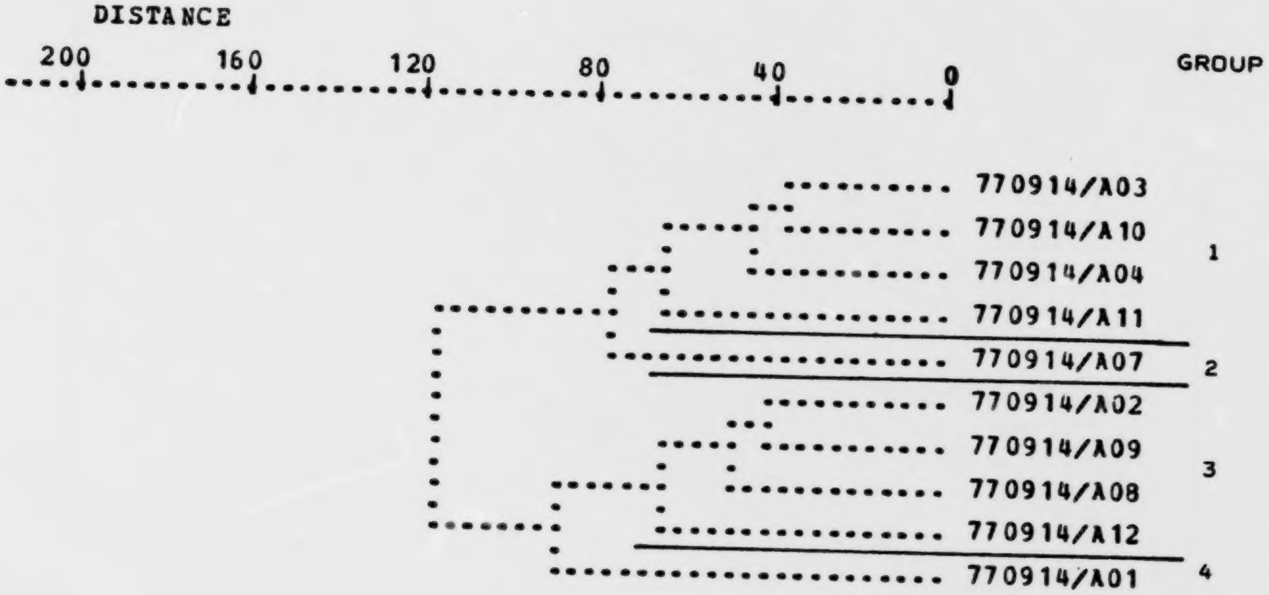
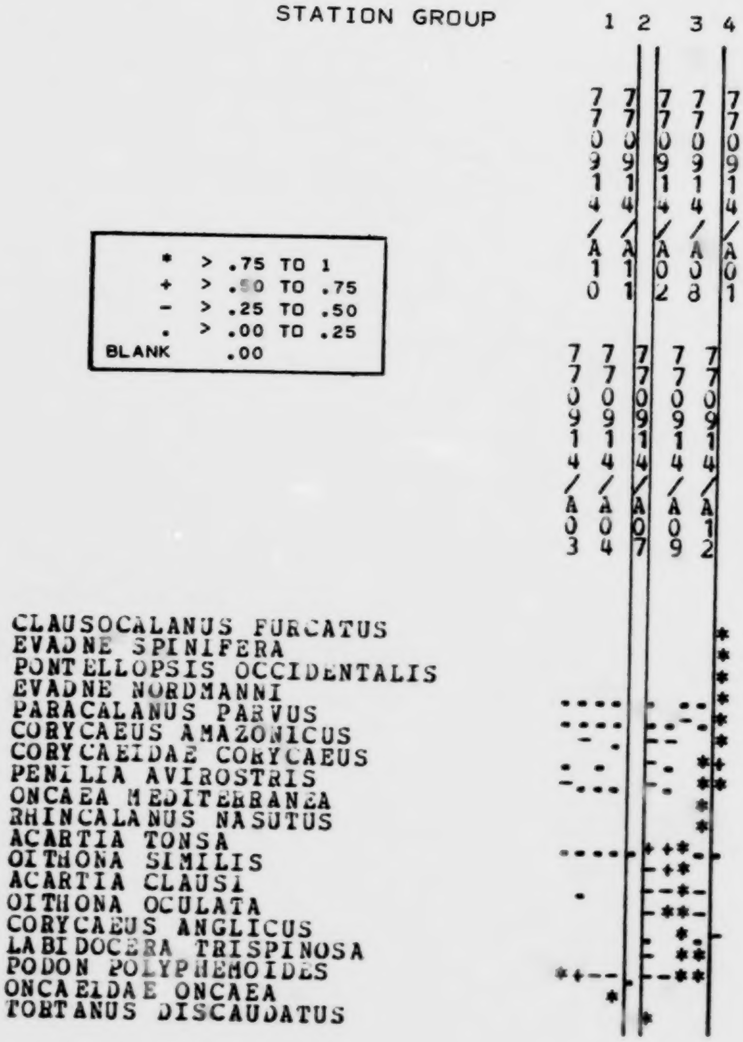


FIGURE 17.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** SEPTEMBER, 1977

*	>	.75	TO	1
+	>	.50	TO	.75
-	>	.25	TO	.50
.	>	.00	TO	.25
BLANK		.00		



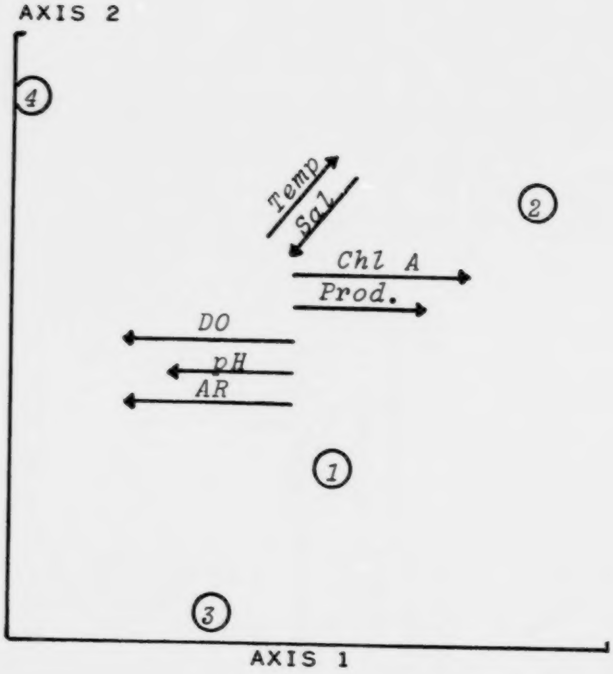


FIGURE 18. PLANKTON STATION GROUPS AND AXES, WITH VECTORS SEPTEMBER 1977

```
TABLE  7.

WEIGHTED GROUP MEANS
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** SEPTEMBER, 1977

                    GROUPS       1          2          3          4

  1. TEMPERATURE             17.9381    18.0017    17.8119    17.8349
  2. SALINITY                32.4201    32.3635    32.4378    32.4163
  3. OXYGEN                   7.4469     7.0707     7.5585     8.0340
  4. PH                       8.0922     8.0742     8.1139     8.1318
  5. PRODUCTIVITY             0.5713     0.6595     0.5485     0.4384
  6. CHLOROPHYLL A            2.5482     3.0815     2.3267     1.6912
  7. ASSIMILATION RATIO       0.2483     0.2163     0.2734     0.4345

** ONE-WAY ANOVA FOR EACH VARIABLE * DF =     3,   36
       VARIABLE                    F
  1.   TEMPERATURE                0.29
  2.   SALINITY                   0.12
  3.   OXYGEN                     0.71
  4.   PH                         0.62
  5.   PRODUCTIVITY               0.18
  6.   CHLOROPHYLL A              0.83
  7.   ASSIMILATION RATIO         0.50
```

TABLE 8.

** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS	ROOT	%	CUM %	CHI SQUARED	DF
1	3.591E-01	74.3	74.3	10.28	9
2	1.003E-01	20.7	95.0	3.20	7
3	2.403E-02	5.0	100.0	0.80	5

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE)) **
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** SEPTEMBER, 1977

AXES	1	2	3
1. TEMPERATURE	2.5	7.9	24.8
2. SALINITY	6.3	18.4	8.1
3. OXYGEN	37.2	14.0	39.2
4. PH	13.4	0.0	15.0
5. PRODUCTIVITY	4.8	10.7	1.8
6. CHLOROPHYLL A	27.1	3.1	10.9
7. ASSIMILATION RATIO	8.6	45.9	0.4

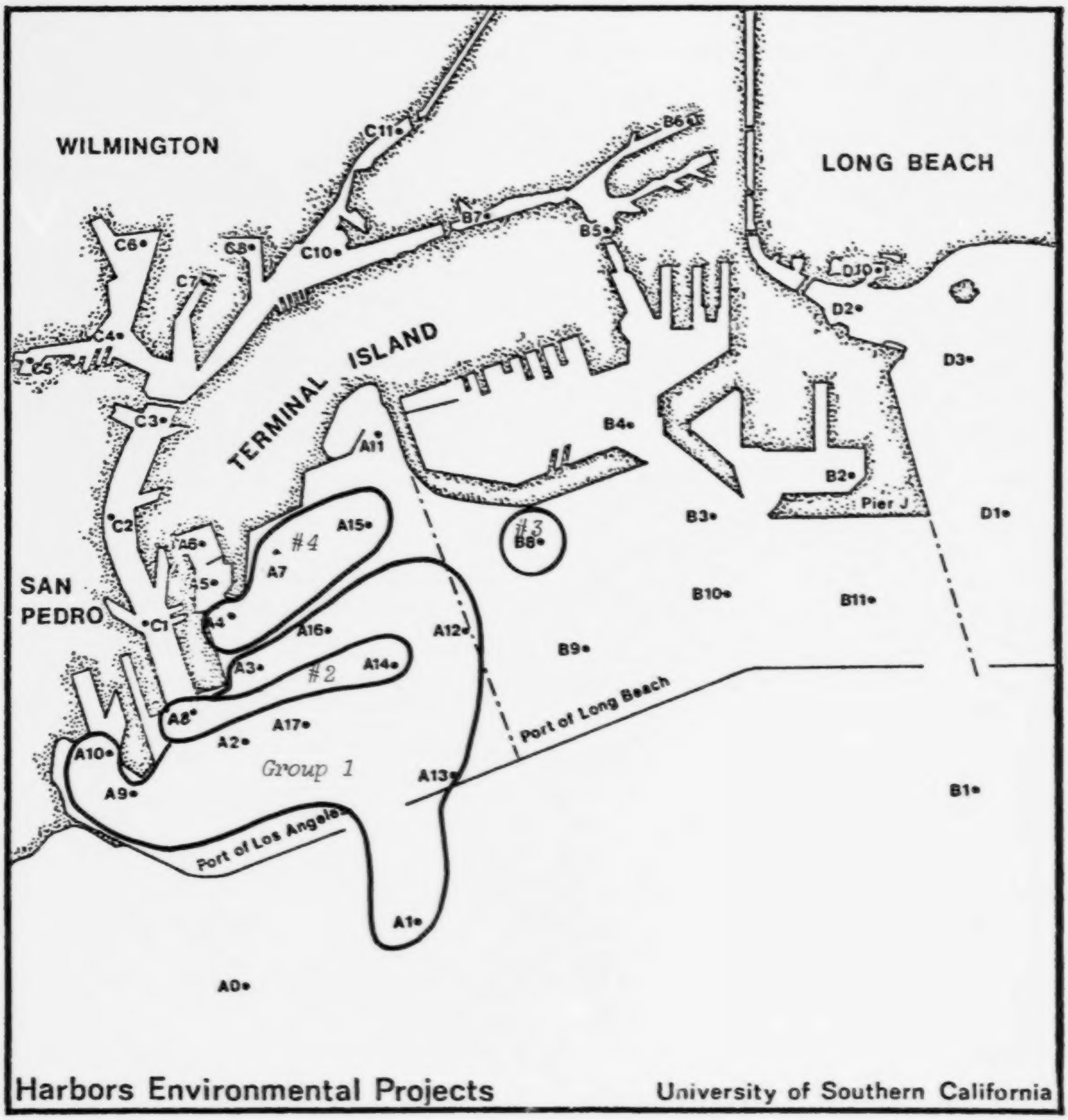


FIGURE 19. PLANKTON STATION GROUPS, DECEMBER 1977

GROUP 1 - A1, A2, A3, A12, A13, A16, A17
GROUP 2 - A8, A14
GROUP 3 - B8
GROUP 4 - A4, A7, A15

FIGURE 20.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** DECEMBER, 1977

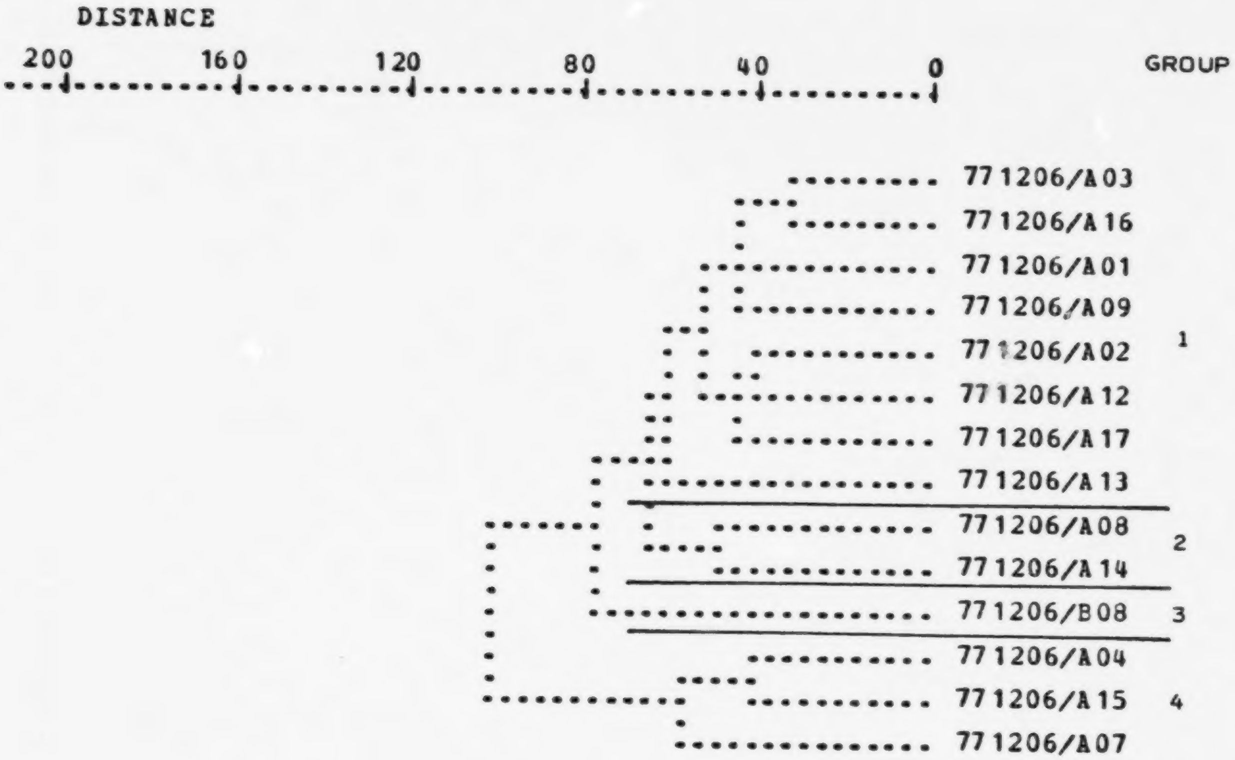
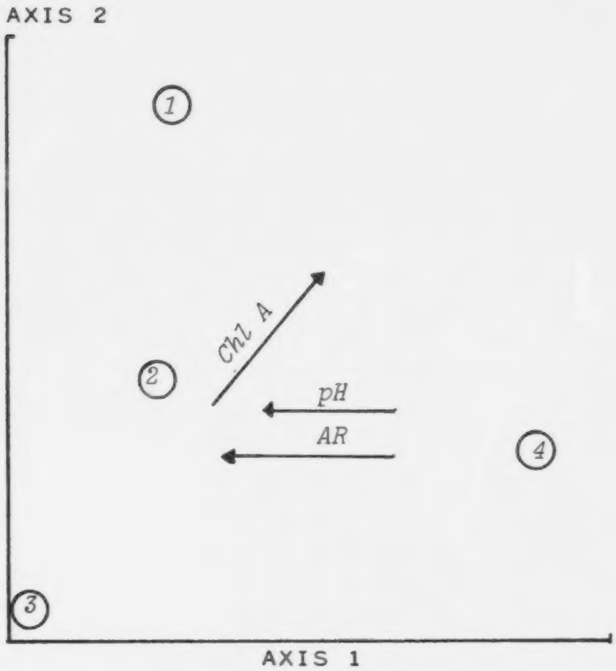


FIGURE 21.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** DECEMBER, 1977

*	> .75	TO	1
+	> .50	TO	.75
–	> .25	TO	.50
.	> .00	TO	.25
BLANK	.00		

STATION GROUP	1								2		3	4		
	771206/A03	771206/A16	771206/A01	771206/A09	771206/A02	771206/A12	771206/A17	771206/A13	771206/A08	771206/A14	771206/B08	771206/A04	771206/A15	771206/A07
ACARTIA CLAUSI											*			
CLAUSOCALANUS PARAPERGENS											*			
OITHONA SPINIROSTRIS											*			
EUCALANIDAE EUCALANUS								*						
TEMORIDAE TEMORA								*						
ONCAEIDAE ONCAEA				+				*						
TORTANUS DISCAUDATUS								*	*					
CORYCAEUS ANGLICUS	-	+	-	-	+	+	+	+	-	+	*	.	.	.
PARACALANUS PARVUS	+	+	+	*	+	*	+	*	*	+	*	.	.	.
ACARTIA TONSA	-	-	-	-	+	+	+	-	+	*	+	.	.	-
LABIDOCERA TRISPINOSA			*	*	*	+	*		*	*	+	.	.	+
CLAUSOCALANUS FURCATUS	+	+	*	.	-		*	*	-	*		.	.	.
ONCAEA VENUSTA	*	*		-	+		+	*		+			.	
PENILIA AVIROSTRIS	+	+	+	-	-	+	*	*	.			.	-	.
TEMORA DISCAUDATA	*	*	*	*		*		*					-	
OITHONA PLUMIFERA	*	-	+	-	-		*							
OITHONIDAE OITHONA	+	-		-	-		*					.	.	
PSEUDOCALANIDAE CLAUSOCALANUS	*		+		+	+	*							
OITHONA OCULATA					*				-			-	.	*
EVADNE NORDMANNI	-	-	.	-	.	-	+	-	.	*		.	.	.
PODON POLYPHEMOIDES	.	.		+	-		-			*		.	.	
CLAUSOCALANUS MASTIGOPHORUS										*				
RHINCALANUS NASUTUS		*	+						-	*				
CLAUSOCALANUS JOBEI							*							
CORYCAEUS AMAZONICUS						*	*					.		
EVADNE SPINIFERA		+	-				*	+	.	-			.	
OITHONA SIMILIS			*				*	+	-					
EUTERPINA ACUTIFRONS			-	*			*		+	+		.	.	
ACARTIA DANAE	*		*	+								-		
ONCAEA MEDIA	*		*											
ONCAEA MEDITERRANEA			*											



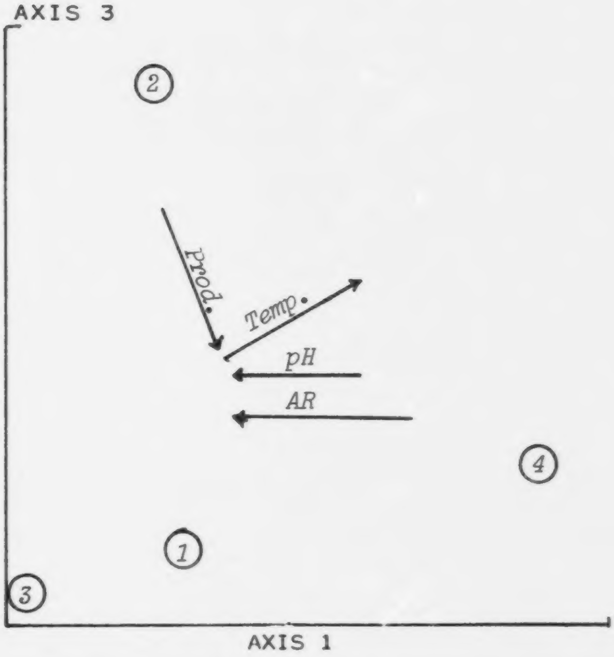


FIGURE 22. PLANKTON STATION GROUPS AND AXES WITH VECTORS
DECEMBER 1977

```
TABLE 9.
WEIGHTED GROUP MEANS
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** DECEMBER, 1977

                    GROUPS       1          2          3          4

  1. TEMPERATURE              17.9188    17.9246    17.8985    17.9250
  2. SALINITY                 34.2526    34.2464    34.2382    34.2074
  3. OXYGEN                    7.4464     7.4929     7.5351     7.5711
  4. PH                        8.1674     8.1738     8.1810     8.1524
  5. PRODUCTIVITY              1.2923     1.2060     1.2461     1.2131
  6. CHLOROPHYLL A             1.2235     1.1333     1.1176     1.2058
  7. ASSIMILATION RATIO        1.2235     1.2351     1.3383     1.1454

** CNE-WAY ANOVA FOR EACH VARIABLE * DF =     3,    52
      VARIABLE                      F
  1.   TEMPERATURE                 0.02
  2.   SALINITY                    0.01
  3.   OXYGEN                      0.01
  4.   PH                          0.05
  5.   PRODUCTIVITY                0.02
  6.   CHLOROPHYLL A               0.02
  7.   ASSIMILATION RATIO          0.08
```

TABLE 10.

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS     ROOT            %        CUM %    CHI SQUARED      DF
  1  2.870E-02         69.2        69.2         1.40          9
  2  8.751E-03         21.1        90.3         0.43          7
  3  4.032E-03          9.7       100.0         0.20          5

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** DECEMBER, 1977

                      AXES        1       2       3

   1. TEMPERATURE                5.3     3.2    27.2
   2. SALINITY                   2.4     7.5     6.1
   3. OXYGEN                     1.6     6.3     4.0
   4. PH                        17.1     3.2     2.9
   5. PRODUCTIVITY              12.6    26.1    25.4
   6. CHLOROPHYLL A             25.1    28.3    23.9
   7. ASSIMILATION RATIO        35.8    25.4    10.5
```

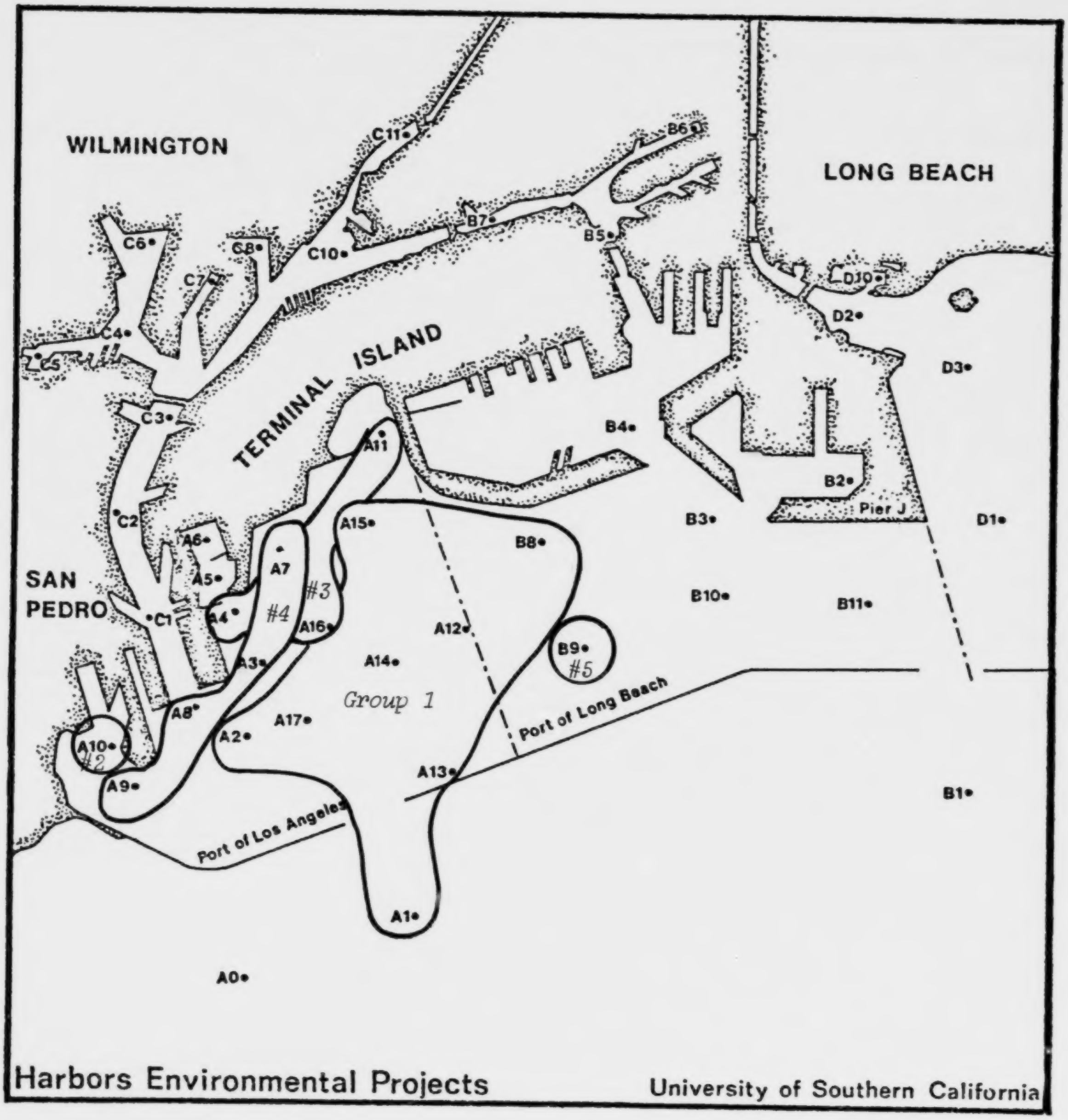


FIGURE 23. PLANKTON STATION GROUPS, APRIL 1978

GROUP 1 - A1, A2, A12, A14, A15, A17, B8
GROUP 2 - A10
GROUP 3 - A4, A11, A16
GROUP 4 - A3, A7, A8, A9
GROUP 5 - B9

FIGURE 24.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** APRIL, 1978

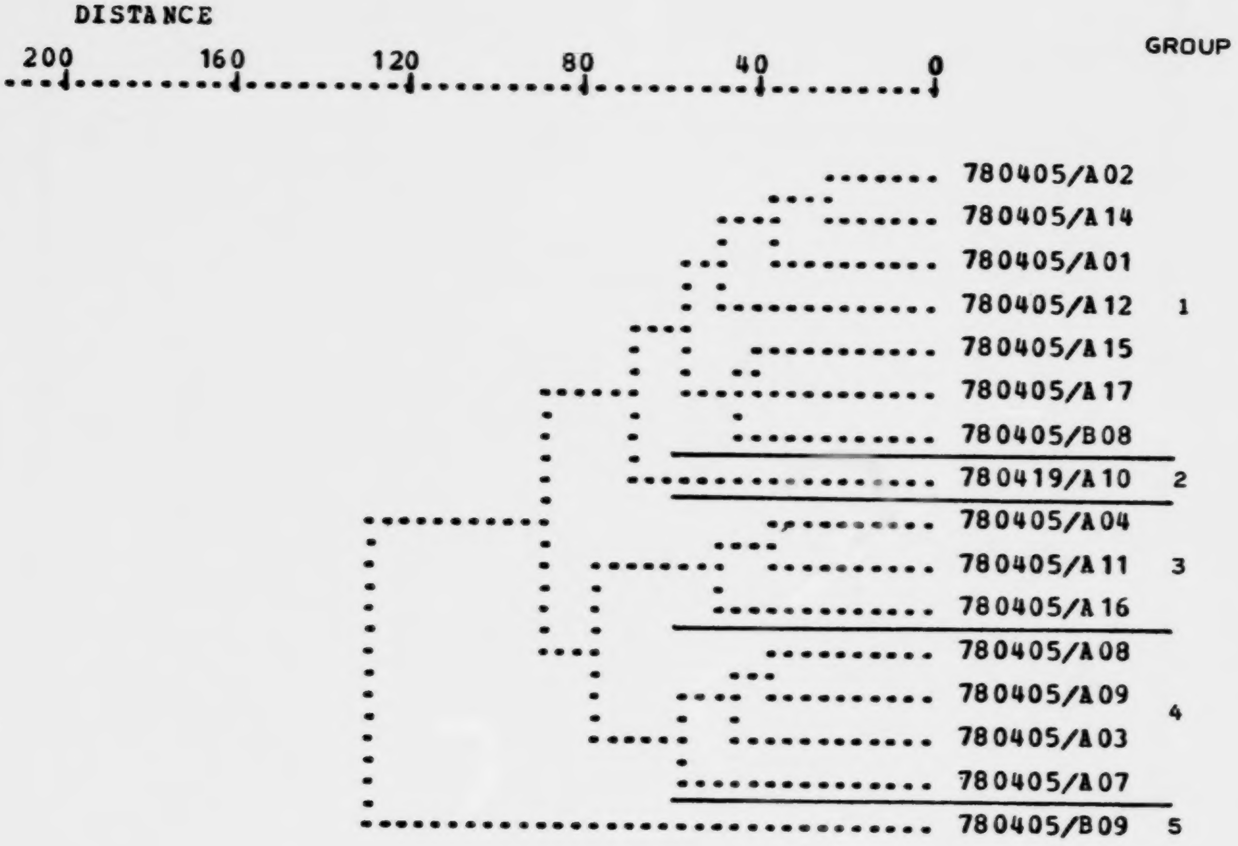
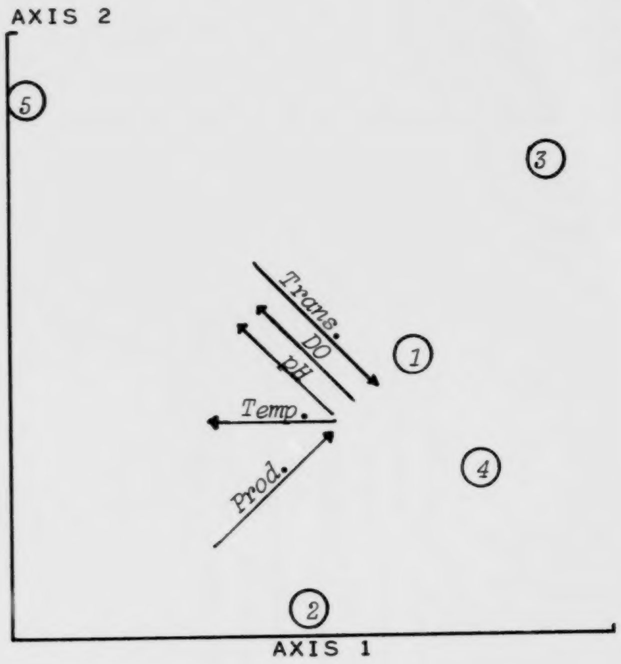


FIGURE 25.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** APRIL, 1978

*	> .75 TO 1
+	> .50 TO .75
-	> .25 TO .50
.	> .00 TO .25
BLANK	.00

STATION GROUP	1							2	3			4				5
	780405/A02	780405/A14	780405/A01	780405/A12	780405/A15	780405/A17	780405/B08	780419/A10	780405/A04	780405/A11	780405/A16	780405/A08	780405/A09	780405/A03	780405/A07	780405/B09
ACARTIA DANAE																*
CALOCALANUS STYLIREMIS																*
CANDACIIDAE CANDACIA																*
CORYCAEUS GIESBRECHTI																*
LABIDOCERA JOLLAE																*
PODON POLYPHEMOIDES																*
PSEUDO-PELTIDIIDAE CLYTEMNESTR																*
CTENOCALANUS VANUS						*										
ONCAEIDAE ONCAEA						*										
RHINCALANUS NASUTUS				*		*										
OITHONA PLUMIFERA	*	+	+													
PSEUDOCALANIDAE CLAUSOCALANUS	+	*	*									.				
TEMORA DISCAUDATA	*	*	-	+												
ACARTIA CLAUSI	*													+		
CORYCAEUS AMAZONICUS	+	.	.		-	-	-				.			.		*
EVADNE SPINIFERA		*														+
EVADNE NORDMANNI	+	-	-	+	-	*		*	+				-	-	-	
PARACALANUS PARVUS	+	-	-	-	*	+	+	*	-	.	-	-	*	-	-	
ACARTIA TONSA	-	-	.	-	-	-	+	+	*	*	+	-	-	-	.	.
EUTERPINA ACUTIFRONS	-	-		.		-	-	*			-	-				
LABIDOCERA TRISPINOSA	-	+	-	-	.	-	-	*	-	-	.		.	.	.	
CORYCAEUS ANGLICUS	+	*	-	*	.	+	*	+			-	+	+			-
PENILIA AVIROSTRIS	+	*	+	*	-	.	+	-	.		-	-	.	.	.	
CORYCAEIDAE CORYCAEUS	*	*	*		*	*	*		+					-		
OITHONIDAE OITHONA			*	+	+	+	+					-	-	-		
CLAUSOCALANUS FURCATUS			-		+	*		*								
OITHONA OCULATA					+			*								+
CALANUS HELGOLANDICUS													*			
TORTANUS DISCAUDATUS								*				+	*	+	-	
OITHONA SIMILIS															*	
ONCAEA VENUSTA							*									



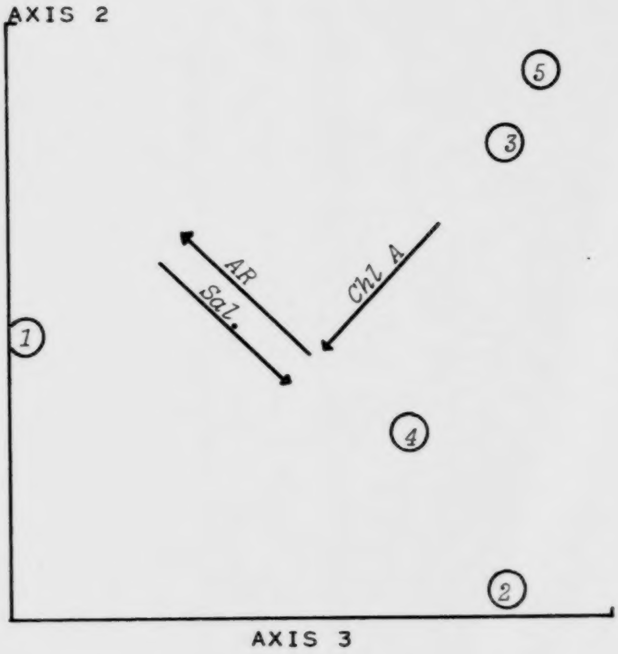


FIGURE 26. PLANKTON STATION GROUPS AND AXES WITH VECTORS
APRIL 1978

TABLE 11.

```
WEIGHTED GROUP MEANS
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** APRIL, 1978

            GROUPS            1          2          3          4          5

  1. TEMPERATURE           17.3622    17.3739    17.2925    17.3472    17.3920
  2. SALINITY              34.3463    34.5700    34.5251    34.5456    34.5262
  3. OXYGEN                10.7981    10.7845    10.7856    10.6503    11.2950
  4. PH                     7.8898     7.8828     7.8623     7.8611     7.9024
  5. %TRANSMITTANCE        47.9610    48.6545    51.1607    49.3359    43.7243
  6. PRODUCTIVITY           4.0545     3.7400     4.0674     3.8385     3.5790
  7. CHLOROPHYLL A          1.7964     1.8225     1.6993     1.7257     3.5790
  8. ASSIMILATION RATIO     2.5422     2.3215     2.5378     2.4596     2.3914

** ONE-WAY ANOVA FOR EACH VARIABLE * DF =    4,   75
      VARIABLE                      F
 1.   TEMPERATURE                  0.05
 2.   SALINITY                     0.03
 3.   OXYGEN                       0.06
 4.   PH                           0.03
 5.   %TRANSMITTANCE               0.06
 6.   PRODUCTIVITY                 0.03
 7.   CHLOROPHYLL A                0.03
 8.   ASSIMILATION RATIO           0.04
```

TABLE 12.

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS     ROOT            %         CUM %    CHI SQUARED       DF
  1   3.236E-02        56.7        56.7         2.31          11
  2   1.382E-02        24.2        81.0         0.99           9
  3   8.338E-03        14.6        95.6         0.60           7
  4   2.516E-03         4.4       100.0         0.18           5


COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** APRIL, 1978

                       AXES          1         2         3         4

   1. TEMPERATURE                 11.2       6.8       7.6       0.4
   2. SALINITY                     1.2       4.6      58.7       2.8
   3. OXYGEN                      18.6       7.1       4.0       0.9
   4. PH                           7.0       0.6       1.6      51.3
   5. %TRANSMITTANCE              34.6       0.3       3.8       1.5
   6. PRODUCTIVITY                 7.1      19.9       0.7      20.2
   7. CHLOROPHYLL A                2.1      35.3       4.4       6.6
   8. ASSIMILATION RATIO          18.3      25.5      19.2      16.3
```

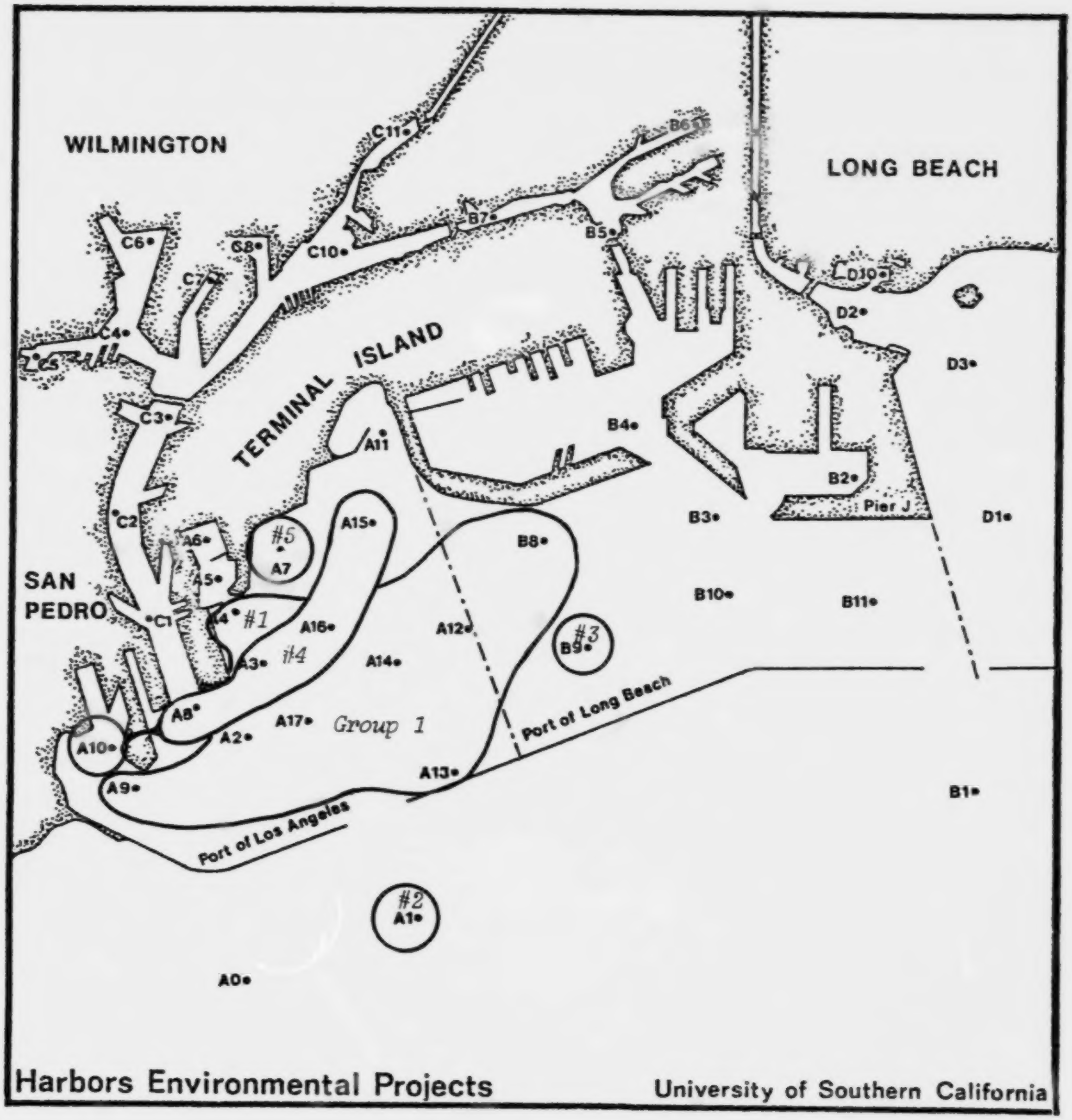


FIGURE 27. PLANKTON STATION GROUPS, JULY 1978

GROUP 1 - A2, A4, A9, A12, A13, A14, A17, B8
GROUP 2 - A1
GROUP 3 - B9
GROUP 4 - A3, A8, A10, A15, A16
GROUP 5 - A7

FIGURE 28.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** JULY, 1978

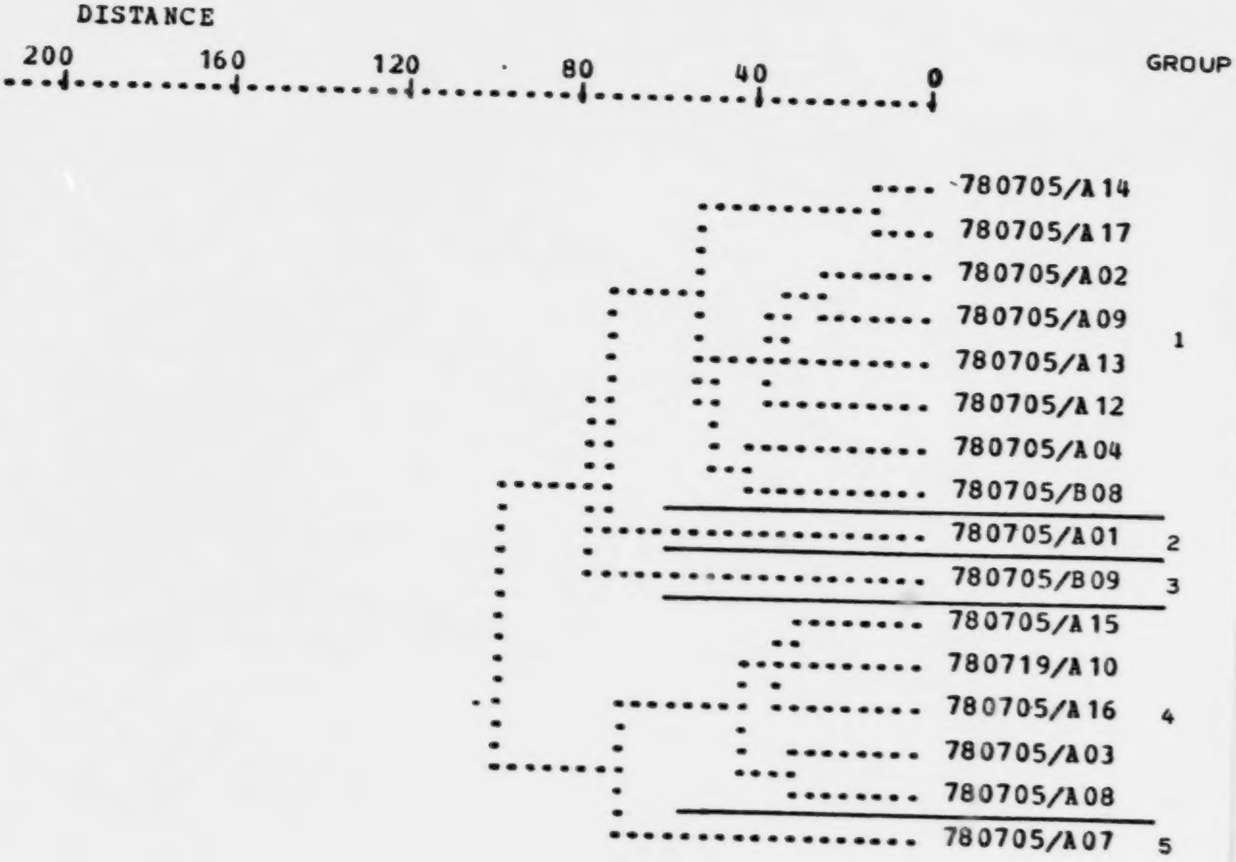
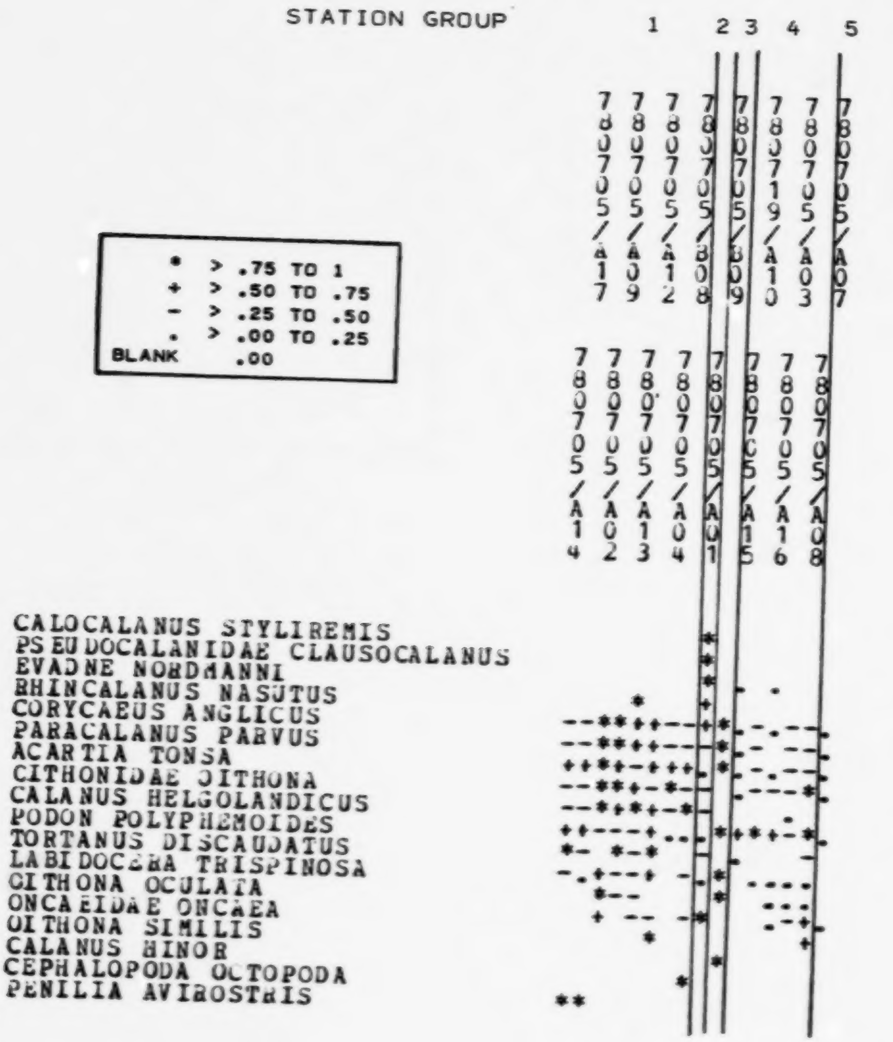


FIGURE 29.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** JULY, 1978



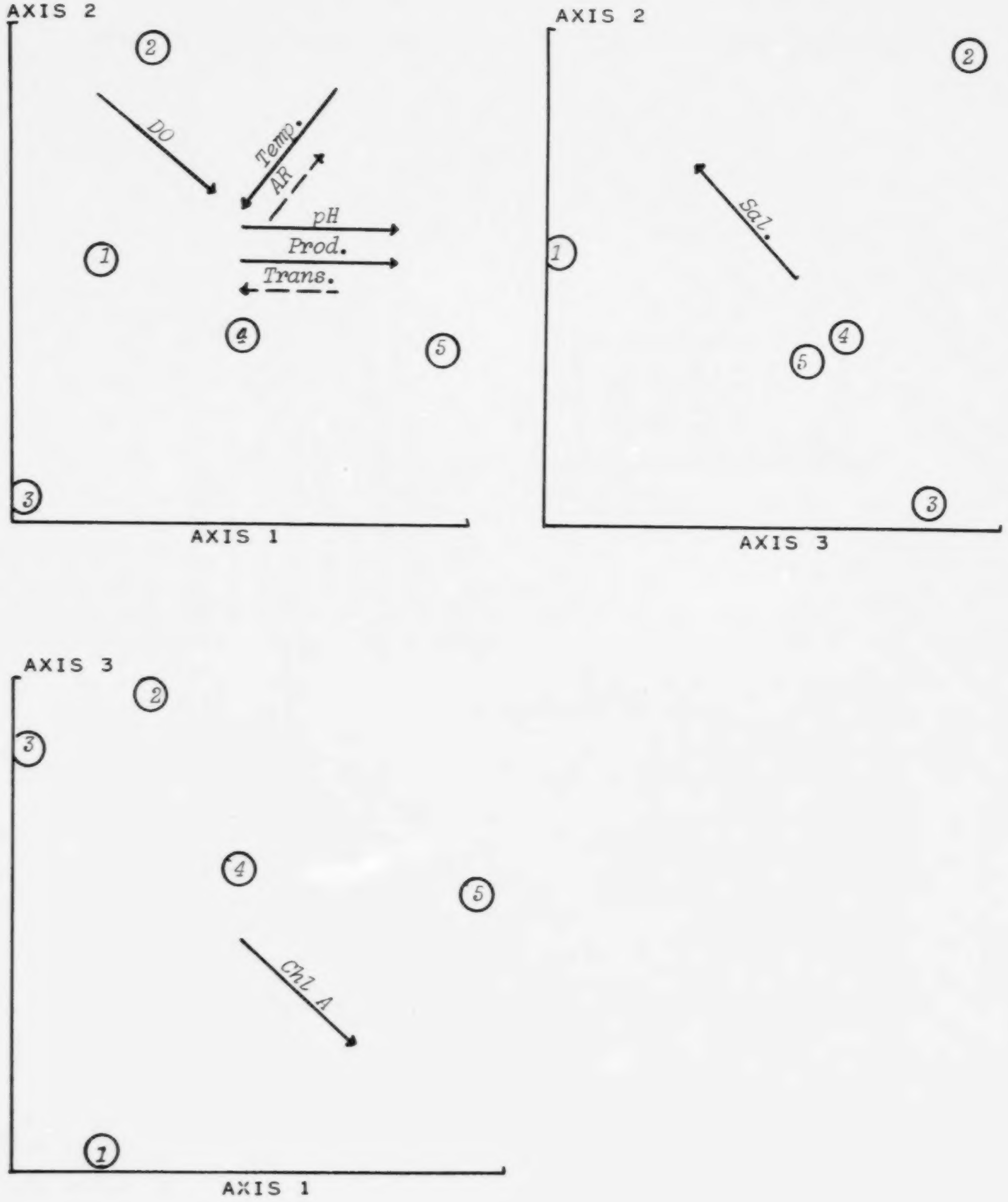


FIGURE 30. PLANKTON STATION GROUPS AND AXES WITH VECTORS JULY 1978

TABLE 13.

```
WEIGHTED GROUP MEANS
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** JULY, 1978

                 GROUPS           1           2           3           4           5

   1. TEMPERATURE           16.3575     16.2665     16.4917     16.3300     16.2695
   2. SALINITY              30.7729     30.7660     30.7453     30.7557     30.7568
   3. OXYGEN                 8.4123      8.3522      8.4349      8.5143      8.5526
   4. PH                     8.3675      8.4052      8.3626      8.4445      8.4913
   5. %TRANSMITTANCE        69.8888     69.8129     70.2844     69.2063     67.0388
   6. PRODUCTIVITY           3.9408      3.9742      3.9073      4.2457      4.9648
   7. CHLOROPHYLL A          4.4884      4.4040      4.3076      4.6488      5.0495
   8. ASSIMILATION RATIO     0.8545      0.8713      0.8521      0.8648      0.9073

** ONE-WAY ANOVA FOR EACH VARIABLE * DF =    4.   75
      VARIABLE                        F
  1.  TEMPERATURE                    0.07
  2.  SALINITY                       0.01
  3.  OXYGEN                         0.04
  4.  PH                             0.04
  5.  %TRANSMITTANCE                 0.11
  6.  PRODUCTIVITY                   0.21
  7.  CHLOROPHYLL A                  0.16
  8.  ASSIMILATION RATIO             0.02
```

TABLE 14.

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS     ROOT             %        CUM %    CHI SQUARED      DF
  1   4.186E-02        72.7        72.7        2.97          11
  2   1.261E-02        21.9        94.5        0.91           9
  3   1.819E-03         3.2        97.7        0.13           7
  4   1.324E-03         2.3       100.0        0.10           5

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** JULY, 1978

                 AXES            1        2        3        4

   1. TEMPERATURE              10.7     57.7      1.6      3.6
   2. SALINITY                  0.1     16.6     16.6      1.4
   3. OXYGEN                    3.2     17.9      1.4     36.8
   4. PH                       10.0      0.5      5.5     21.5
   5. %TRANSMITTANCE            7.2      0.7      5.0      1.3
   6. PRODUCTIVITY             62.5      2.0      6.2     34.4
   7. CHLOROPHYLL A             0.6      4.6     59.0      0.4
   8. ASSIMILATION RATIO        5.8      0.1      4.6      0.8
```

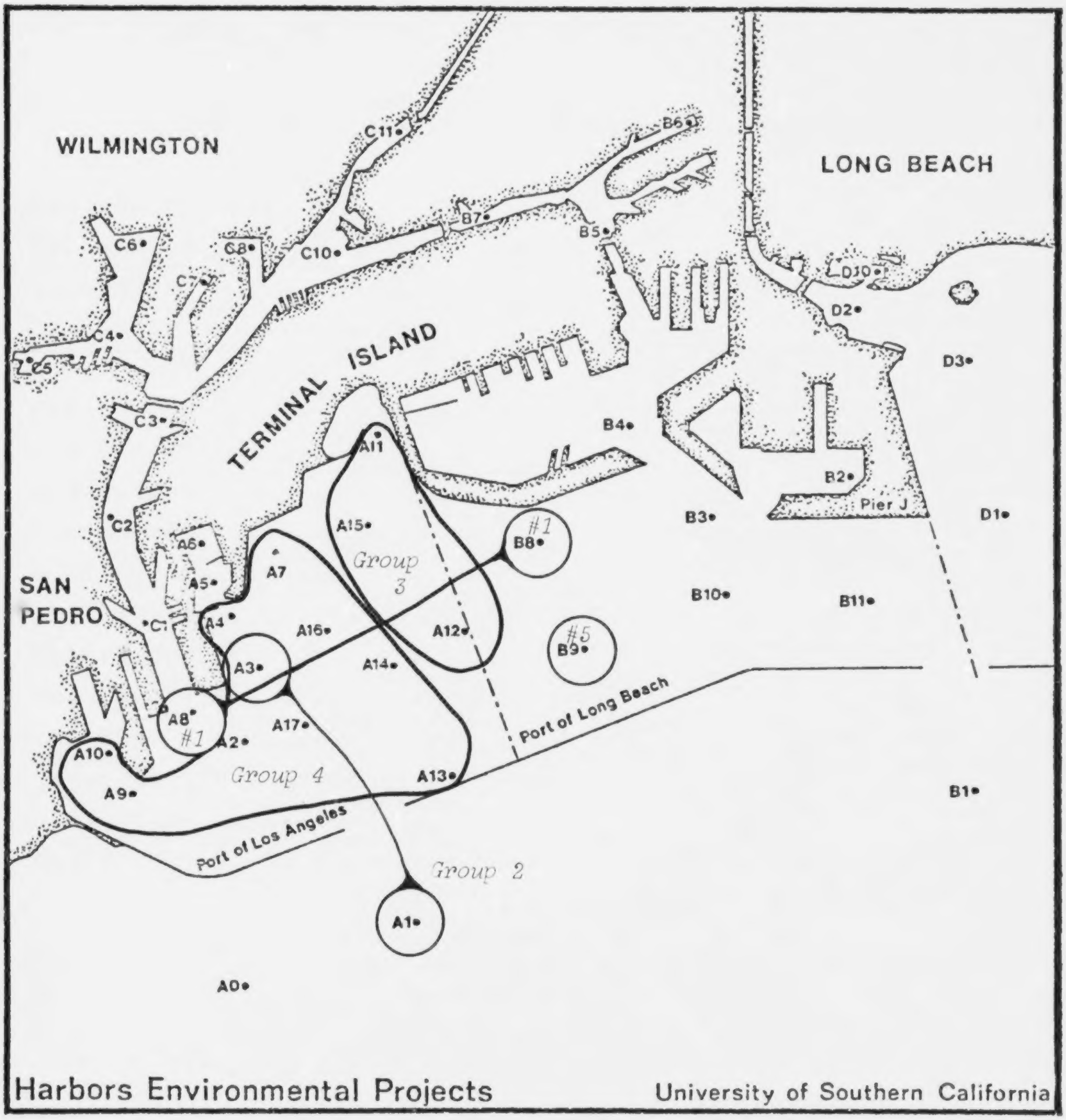


FIGURE 31. PLANKTON STATION GROUPS, SEPTEMBER 1978

GROUP 1 - A8, B8
GROUP 2 - A1, A3
GROUP 3 - A11, A12, A15
GROUP 4 - A2, A4, A7, A9, A10, A13, A14, A16, A17
GROUP 5 - B9

FIGURE 32.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** SEPTEMBER, 1978

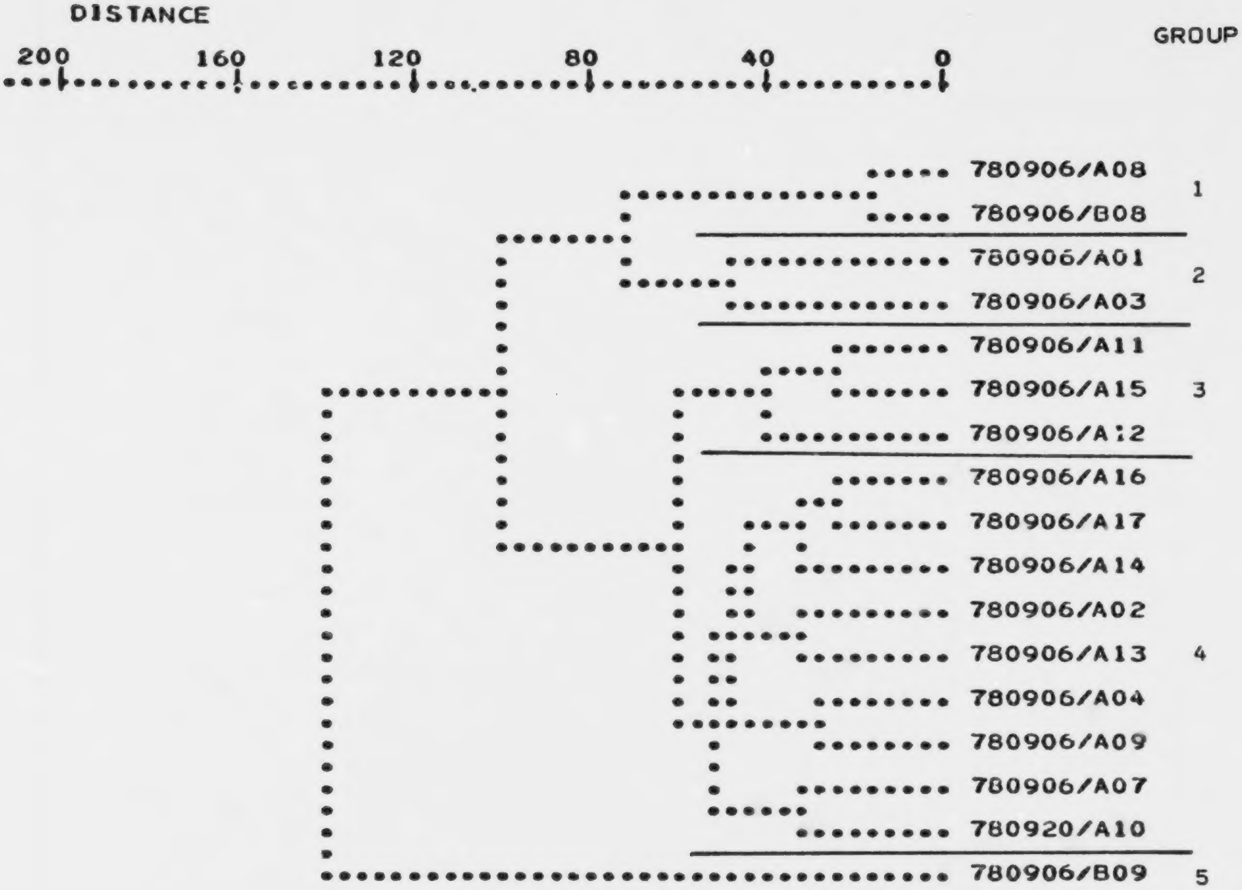
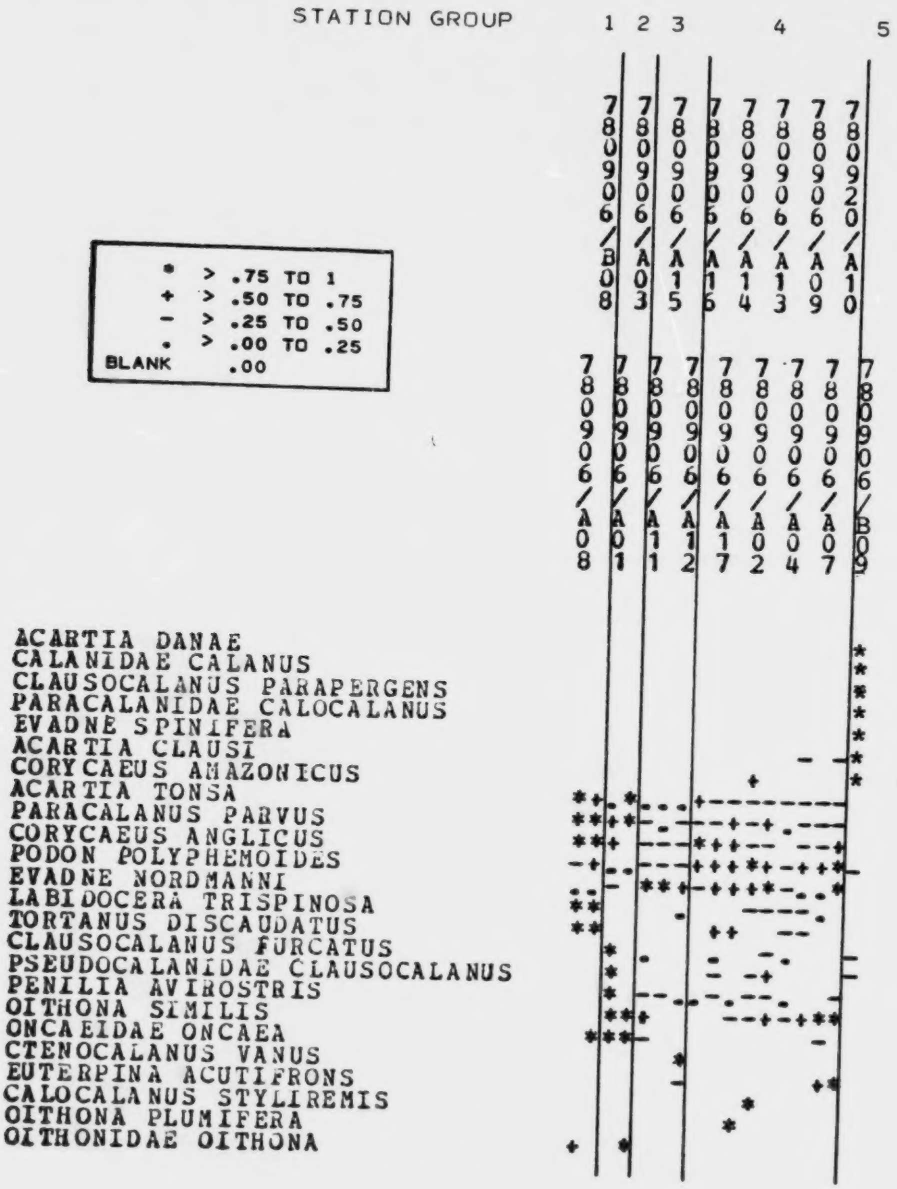


Figure 33.

TERMINAL ISLAND TREATMENT PLANT PLANKTON ** SEPTEMBER, 1978



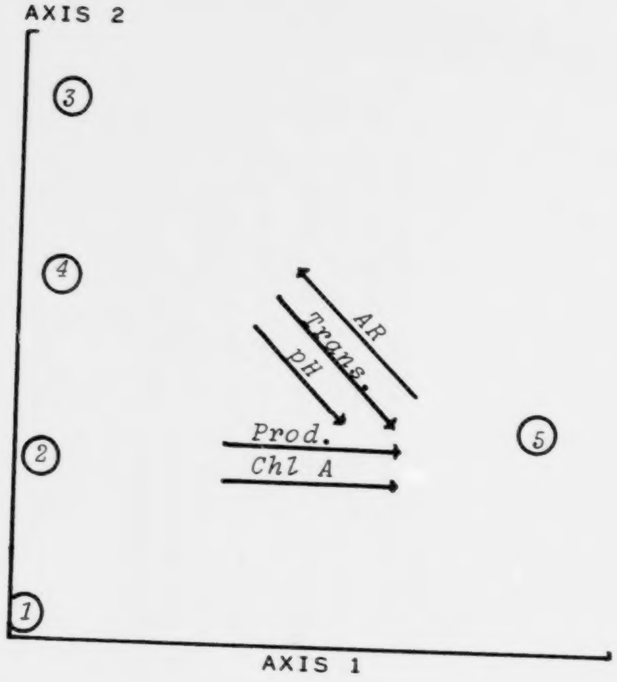


FIGURE 39. PLANKTON STATION GROUPS AND AXES WITH VECTORS SEPTEMBER 1978

TABLE 15.

```
WEIGHTED GROUP MEANS
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** SEPTEMBER, 1978

               GROUPS          1          2          3          4          5

   1. PRODUCTIVITY       13.5821    13.7280    15.3931    14.8704    23.3289
   2. CHLOROPHYLL A       3.7622     3.7423     3.8953     3.9099     7.5790
   3. ASSIMILATION RATIO  3.6650     3.7624     4.0033     3.8597     3.2790
   4. TEMPERATURE        18.4425    18.4874    18.4778    18.4761    18.3199
   5. SALINITY           30.5836    30.5803    30.5929    30.5871    30.6425
   6. OXYGEN              6.3784     6.3445     6.3704     6.3597     6.6832
   7. PH                  8.5351     8.5203     8.5419     8.5346     8.6163
   8. %TRANSMITTANCE     64.9639    62.9756    64.5029    64.1015    68.7297

** ONE-WAY ANOVA FOR EACH VARIABLE * DF =    4,   80
      VARIABLE                    F
   1.  PRODUCTIVITY             0.58
   2.  CHLOROPHYLL A            1.35
   3.  ASSIMILATION RATIO       0.17
   4.  TEMPERATURE              0.03
   5.  SALINITY                 0.03
   6.  OXYGEN                   0.09
   7.  PH                       0.08
   8.  %TRANSMITTANCE           0.04
```

TABLE 16.

** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS	ROOT	%	CUM %	CHI SQUARED	DF
1	3.665E-01	92.9	92.9	24.20	11
2	2.133E-02	5.4	98.3	1.64	9
3	6.110E-03	1.5	99.9	0.47	7
4	4.506E-04	0.1	100.0	0.03	5

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE)) **
TERMINAL ISLAND TREATMENT PLANT PLANKTON ** SEPTEMBER, 1978

AXES	1	2	3	4
1. PRODUCTIVITY	26.7	26.1	27.9	10.9
2. CHLOROPHYLL A	60.1	0.0	19.1	19.6
3. ASSIMILATION RATIO	5.1	61.4	3.1	39.7
4. TEMPERATURE	2.9	4.6	7.1	3.0
5. SALINITY	0.4	1.5	4.0	5.0
6. OXYGEN	0.3	4.3	6.0	11.6
7. PH	4.0	1.7	11.6	0.8
8. %TRANSMITTANCE	0.5	0.4	21.3	9.5

WEIGHTED DISCRIMINANT ANALYSIS OF BENTHIC DATA

Computer programs developed for ecological analysis in Los Angeles Harbor were first used on the 1973-74 benthic data (AHF, 1976). In that report, 34 benthic stations were sampled quarterly in the two harbors. Discriminant analysis showed a pattern (1976, Figure 6.3) based on annual data of inner blind-end slips, main channel, outer harbor and polluted zone faunal separations. Henry (1976) and Soule and Oguri (1978) showed that seasonality existed in benthic faunal composition, which had previously been underestimated or disregarded. Therefore, the quarterly benthic data from December 1976 have been analyzed in the present report.

RESULTS

December 1976.

Twelve A stations were sampled in December 1976 in outer Los Angeles Harbor. The station groupings (Figures 1 and 2) could very well be viewed as being separated by depth and distance from the shorelines, in fairly typical winter season patterns.

The Two-Way Table (TWT, Figure 3) provides information that the number of species was very low at A4 and A7, whereas A1 had a number of species not seen at other stations. The weighted group means are presented in Table 1, and the coefficients of separate determination are given in Table 2. The coefficients show that the physical variables did affect separation, primarily by salinity, and less so by dissolved oxygen, temperature and depth, but the biological variables for productivity and assimilation ratio were also of prime importance.

Group 1 stations had the highest weighted means for productivity and assimilation ratio and the highest salinity and dissolved oxygen. Group 2 stations had the next highest. Group 4, the outfalls, had the lowest weighted mean temperature, lowest salinity, DO and assimilation ratio, and is the shallowest as well. Group 3 (the sea buoy) had the highest temperature and lowest productivity. The coefficients showed that Axis 1 contained 66.9% of the information, but Axes 2 and 3 were also effective in separation. Figure 4 shows the separation of the groups according to vectors for the particular parameters which could be diagrammed on the axes. Usually only those with coefficients of ten or above are indicated on the figure of the vectors.

March 1977.

Groupings for this period appeared to be somewhat similar to the December 1976 separations, ranging from shoreline to outside the harbor. However, Groups 1 and 3 overlapped, due to the inclusion of station A4 with outer harbor Group 3 (Figures 5 and 6). The isolation of Group 2 (station A1) is not unexpected, since it had the lowest weighted mean temperature as well as the greatest depth. It also had the lowest chlorophyll *a* values (Table 3).

Examination of the coefficients of separate determination show that pH values were most important on Axis 1 (Table 4) and helped to isolate the sewer outfall (group 4, station A7). Group 1 was the highest and group 4 the lowest in salinity, dissolved oxygen, pH, primary productivity and assimilation ratio. The outfall (group 4) was highest in temperature and chlorophyll *a* values, the latter also having a high coefficient on Axis 1. Diversity was very poor at the outfall area, and large gaps in benthic species can be seen in Group 3 fauna in the TWT (Figure 7). Groups 2 and 3 varied in the intermediate rankings of the various parameters. Group 3 was very close to group in temperature, DO and productivity, which may account for the overlap. The separation is so pronounced for the outfall area that it masks the other trends. If the intent of the analysis were not to characterize the effects of the outfalls, but rather to describe the characteristics of the other stations, the analysis would have been repeated without the A7 data in order to create maximal separation of the other stations (Figure 8). Although Axis 1 contains 99% of the separation values, temperature and productivity dominate Axes 2 and 3 (Table 4). However, the vectors of parameters measured cannot be plotted on those axes alone.

The dissolved oxygen and phytoplankton measurements suggest that a bloom was in progress. This is confirmed by comparison with December data (Table 1) and with section IIC on primary productivity. The weighted means of the phytoplankton variables (Table 3) show pronounced separations, particularly between Groups 1 and 4, which are in fact nearest physically.

The rainfall for the winter of 1976-77 was considerably below normal and may have affected the harbor life cycles in unknown ways.

June 1977

The beginning of secondary waste treatment in April 1977 may or may not have affected the benthic populations in the outer harbor. However, in section IIE, Figures 6 and 7 showed that the number of species dropped sharply by June, except at

A2 and A7 which were already low, while the numbers of organisms increased except at A1 and A9.

Figures 9 and 10 show the isolation into separate groups of several stations, except for those clustered in the central gyre of the outer harbor (Group 1). That group seems to be the richest (TWT, Figure 11). The outfall area had a few more species than before, and A1 no longer stood alone, as it frequently does in the winter.

The weighted group means (Table 5) showed that the outfalls area (Group 5) was highest in temperature, productivity and chlorophyll *a* and lowest in salinity, dissolved oxygen, pH and assimilation ratio. The pH, salinity and oxygen levels were not low enough to be considered limiting, and their relatively low coefficients of separate determination (Table 6) show that these were not important factors. Depth and temperature were much more important, since they are represented by high coefficients. Chlorophyll *a* values were by far the most important of the biological values measured.

Group 1 stations were highest in salinity, pH and assimilation ratio and lowest in productivity. The values for the ther groups were mixed in ranking. Group 2 (station A9) was lowest in productivity, which may reflect the lingering effects of the *Sansinena* tanker explosion and Bunker C spill that occurred six months earlier at that location.

September 1977.

The stations for September 1977 were divided into five groups with some overlap and spatial separation (Figures 13 and 14). However, the most extreme contrast was between Group 5, the outfalls area, and Group 1, the outermost harbor stations. Groups 2, 3 and 4 were so similar to Group 1, in contrast to the outfalls, that separation was difficult. The weighted means (Table 7) and coefficients of separate determination (Table 8) show that the phytoplankton measurements were very low, and only assimilation ratio was an important coefficient in separation on Axis 2. The outfall was poor in species also (TWT, Figure 15). Weighted means of Group 5 showed that the outfalls area had the highest pH and salinity and least depth; it also had the highest productivity and chlorophyll *a* and the lowest assimilation ratio. Vectors are shown in Figure 16. The variability in salinity from month to month at the outfall at times has been due to rainfall runoff (there were 2+ inches in mid-August 1977), or to the amount of cannery wastes processed. Cannery wastes may be highly saline because of the freezing brines from boat holds; this was formerly diluted during processing. The salinity coefficient was one of the most important coefficients on Axis 1, along with depth and then pH. The salinities were not low enough to have great impact, but the rain in August could have favored opportunistic species such as *Capitella capitata*. Salinities were about 1.8 ppt lower than in July 1977.

It is surprising to see such low phytoplankton measurements over the entire outer harbor, when fall peaks would normally have been building, perhaps giving an indication of the inhibitory impact of alterations in the character of the TITP and cannery wastes. The benthic species and numbers appear to be reudced as well.

January 1978. Harbor grouping appeared to be fairly typical of winter, with concentric outer harbor bands and with the sea buoy (group 3) isolated. By January 1978 both cannery effluent lines had been diverted to TITP. Some biostimulation may have been occurring in the A9 area of the *Sansinena* (Figures 17 and 18) at Group 1 stations; the TWT (Figure 19) also suggests this. However, the weighted means (Table 9) show Group 1 as highest in temperature, salinity, DO and pH. Phytoplankton measures were all low. The coefficients (Table 10) showed that phytoplankton measures were not as important as the physical measures, except for assimilation ratio. Group 5, the outfall area, was isolated by having the lowest weighted mean salinity, temperature and DO (Table 9) even though salinities were quite low at all stations.

A heavy rainfall of 1.5± in. was in progress during actual benthic sampling, lowering all salinity values in the harbor. Heavy rainfall runoff appears to lower DO in the harbors, as was documented in Marina del Rey for storm flows (Soule and Oguri, 1976). The pH weighted mean was lowest at the sea station A1 (Group 3), but productivity and chlorophyll were higher there. In Table 10 the coefficients of separate determination especially emphasize the physical parameters of pH (73.9% on Axis 2), oxygen (56.5% on Axis 1), temperature, and salinity.

The impacts of rainfall have not been well documented, but would not be expected to affect benthic organisms except, for example, at the outfalls area (group 5) where storm runoff goes through TITP. Stone and Reish (1965) documented the effects of rainfall on benthic organisms at the mouth of the Los Angeles River, and Soule and Oguri (unpublished data) noted the removal of benthic organisms and recolonization in Dominguez Channel (Shell Corp. Pipeline Crossing EIR). Opportunistic species recolonize in a matter of a few weeks in the area where existing sediments were carried away and new ones deposited (Soule and Oguri, 1976). Such an area may support only a few species that are euryhaline and have year-round reproductive cycles, such as *Capitella* This is even more the case where the character of the effluent is varying widely, as it was with all the alterations in waste disposal treatment in 1977-78 (see section IIE). Prior years had not shown such extreme domination in 1973-74 (AHF, 1976).

April 1978.

The trends in the harbor in April 1978 were difficult to interpret, with only Group 3, nearest the outfall, clearly separated (Figures 21 and 22). The other two groups overlapped extensively. Group 3 (stations A4 and A7) had the highest weighted mean temperatures and the lowest dissolved oxygen and light transmittance. However, oxygen readings were high, almost as they are at the beginning of a bloom, but more probably due to mixing from storms and high tides. While group 3 had the highest phytoplankton measurements, all chlorophyll *a* and productivity readings were quite low for the season. There is usually a spring peak, but in April 1978 the weighted mean values (Table 11) were more like the winter lows of December 1976 and January 1978 (Tables 1 and 9) than they resembled the spring 1977 values. The unusual rainfall of about 27 inches (unofficial) between January and April probably was responsible. Normal rainfall is about 14 in. a year.

Chlorination was carried on at TITP from the end of March through August 1978, and this might have been partly responsible for the very low assimilation ratio, which indicates stress. However, the imemdiate outfalls area seemed to have slightly better levels of chlorophyll *a* than the rest of the harbor, suggesting that the drop was not caused by TITP but by natural weather conditions. It appears that the entire coastal area was involved, as shown by party boat fish catches (IIA), which were down outside the harbor even though there were actually only four days of measurable rain in April in contrast to about 10 days in January, and 11 each in February and March. The benthos, phytoplankton, zooplankton and fish inside the harbor were all lower than would be expected, and no spring reproductive surge could be seen. Sea temperatures had remained quite warm through the spring until early summer, with a late cooling period. Thus the change in temperature necessary as a reproductive cue in many organisms (Vernberg et al. 1977) was out of phase. The combination of factors, or some parameters not measured, were responsible for the widespread cumulative decrease in organisms. Salinities were higher in April in the harbor than in January, in spite of the rains, suggesting an influx of coastal water, and pH was lower than usual. All of the coefficients (Table 12) of variables measured were moderately important except for chlorophyll *a*, but no single coefficient was very high except for pH; it is usually 8 or above in the harbor except in stressed areas. Group 2 strongly suggests the gyre water, with an influx of water with the highest salinity, oxygen and transparency into the harbor. Group 1 is probably the residual water of lower salinity that became the center of the gyre or pooled.

July 1978.

In contrast to the obvious impact of natural conditions in April, July patterns clearly showed the effects of the breakdown at TITP, but not necessarily negative ones. The harbor showed one large station group overlapping another and several single station isolates (Figures 25, 26). There was a reduction in species (Figure 11) at station 4 (Group 4) over June 1977, but an increase at A7 (Group 5) in July 1978 (TWT, Figure 27). Over all, species numbers were up over the previous July.

While benthic organisms would not seem to be as affected as plankton by the variabilities in the water column, it appears that the opposite is the case. The TITP breakdown in July increased the nutrients and bacteria in the water column. Salinities and temperature were lower than they were in April and were significant (Tables 13, 14), but dissolved oxygen was the most important variable according to the coefficients. Dissolved oxygen was below 5 ppm in Group 3 in an area where floating solids had collected, and Group 1, a large area, was next lowest. The outfall itself (Group 5, A7) had the highest DO, but this was only slightly higher than the others, and all were below mean 6 ppm. Station 4 was highest in weighted mean phytoplankton measures and Group 1 was the lowest, but these were all very low for summer. The increase in species and numbers at A7 (Group 5) is unexpected, since sudden changes in effluent character might have been inhibitory. High DO and pH may have been due to control efforts. The group 4 isolate is peculiar in that the three phytoplankton measurements, all with significant coefficients, were not normally proportional. Group 2, composed of two isolated stations, appeared to be linked only because they were intermediate in almost all parameters. However, both had the highest salinity and second highest DO, suggesting ocean influence. Group 3 stations appeared to be more heavily impacted in terms of species (TWT, Figure 27), than Group 1, even though Group 1 had the lowest phytoplankton measures.

October 1978.

Prior to the final benthic sampling for TITP, the plant upset had apparently been brought under control, in part by added aeration, and dissolved oxygen had risen somewhat. In the October station groups (Figures 29, 30) station A1 was separated outside the harbor, and there were almost concentric arcs out from TITP. Most interesting is Group 5 (A14), which lies at about the center of the large harbor gyre. Vorticity apparently led to deposition, for the TWT (Figure 31) shows this formerly rich benthic area to have been severely depleted, perhaps by the rapid changes in nutrients and probably in controlling substances such as chlorination. However, A14 was higher in chlorophyll *a* (Tables 15, 16) than the other stations, even though all are low for the fall; A14 was also the highest in mean temperature. The physical variables, however, did not have significant coefficients, whereas the phytoplankton measures did.

Group 3, the outfall area, had the lowest weighted means for DO, pH, productivity and assimilation ratio. Yet the two stations had a significant increase in colonization, as shown on the TWT. This perhaps emphasizes that variability, whether natural or man-made, has a stimulatory effect on estuarine species when toxicity is not a problem. There are no indications that normal TITP effluent is toxic (Section V).

For the first time since June 1977 the three phytoplankton parameters assumed the major importance, even though the levels were relatively low as compared with pre-secondary treatment years. Groups 1 and 2 were intermediate in most parameters. However, separations were clear in that Group 2 had higher phytoplankton measurements than group 1.

LITERATURE CITED: See Section VIA.

METHODS SECTION, DISCRIMINANT ANALYSIS: See Section VIB.

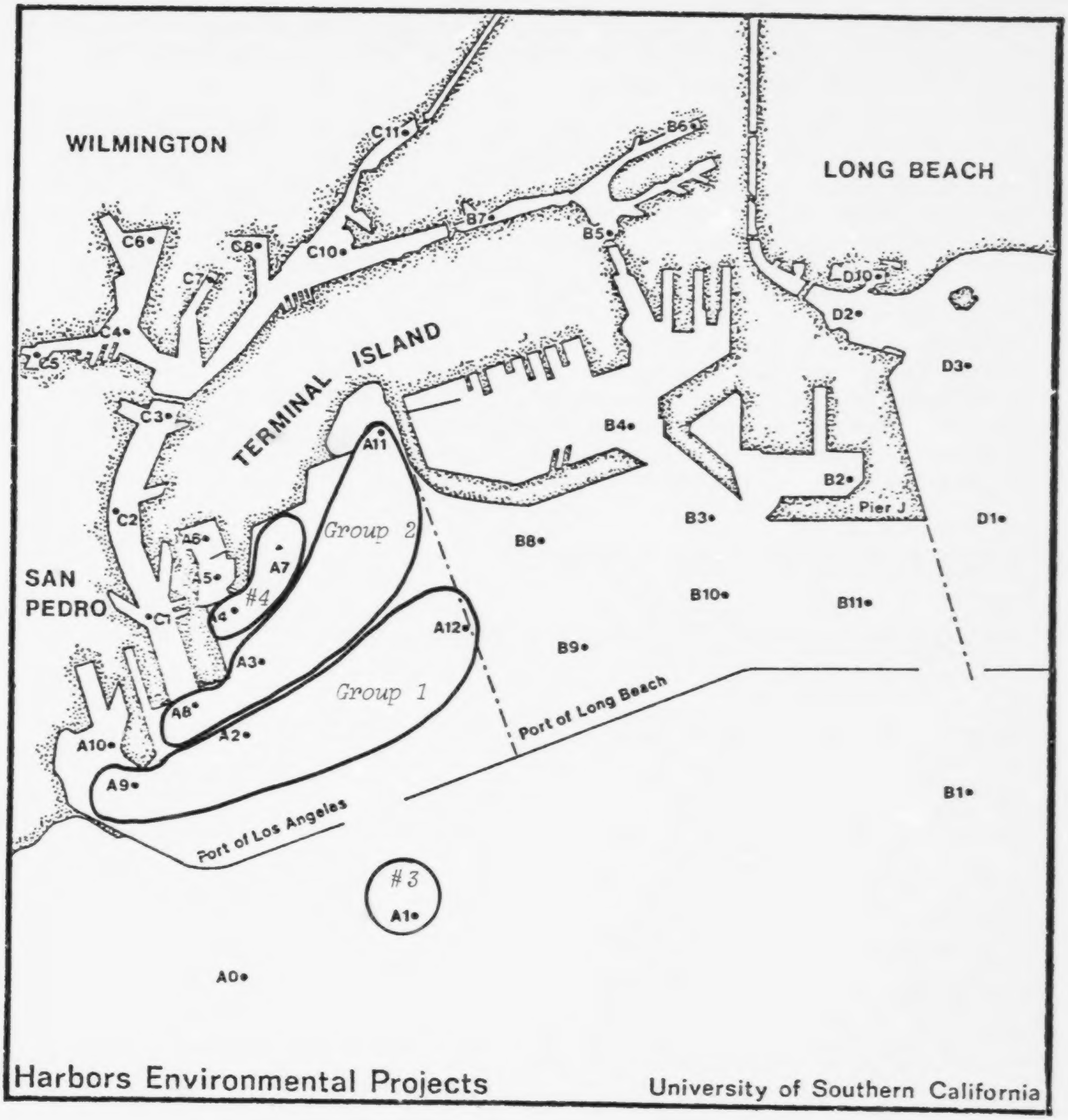
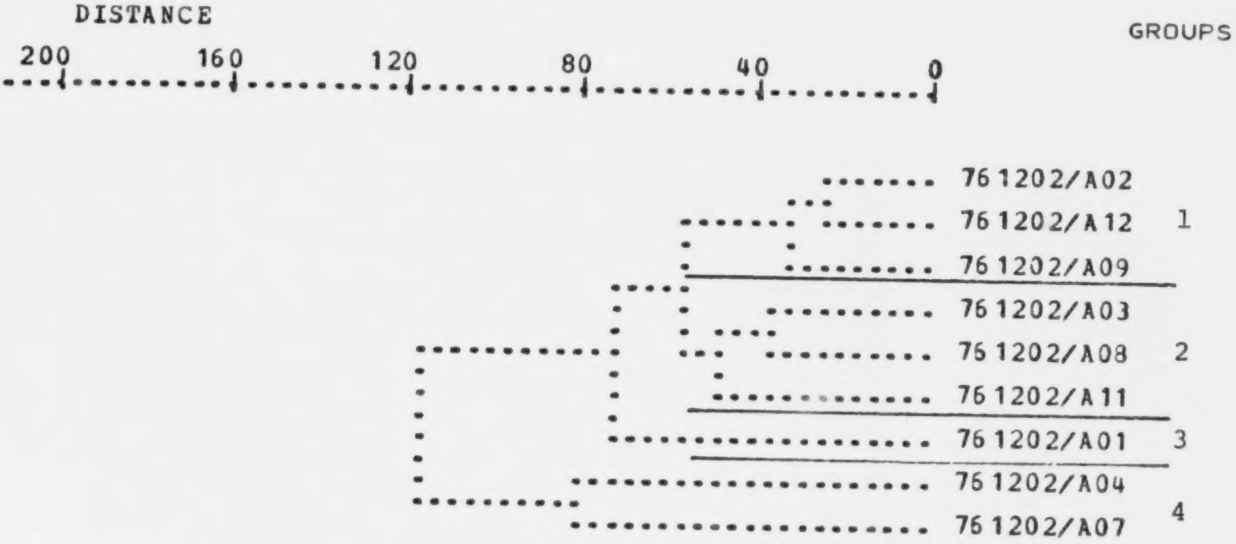


FIGURE 1. BENTHIC STATION GROUPS, DECEMBER 1976.

GROUP 1 - A2, A12, A9
GROUP 2 - A3, A8, A11
GROUP 3 - A1
GROUP 4 - A4, A7

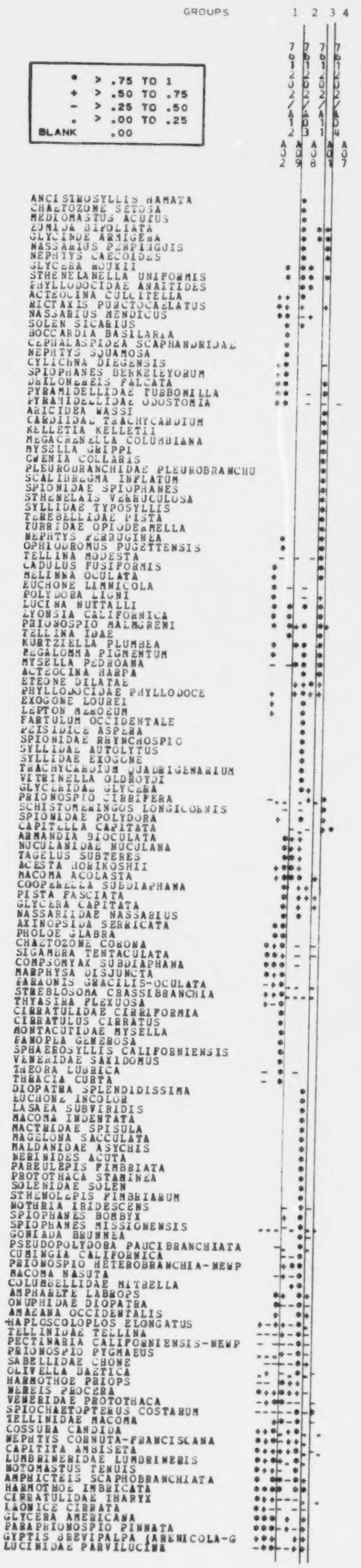
FIGURE 2.

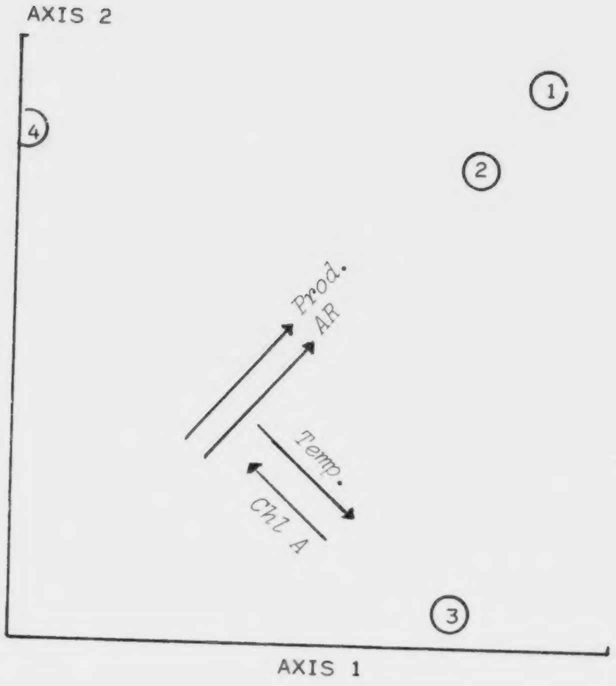
TERMINAL ISLAND TREATMENT PLANT BENTHICS ** DECEMBER, 1976



TERMINAL ISLAND TREATMENT PLANT BENTHICS ** DECEMBER, 1976

FIGURE 3.





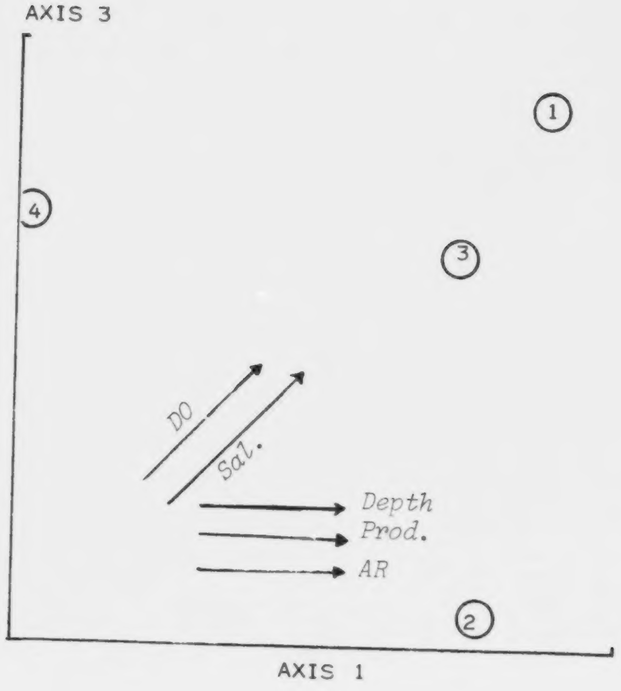


FIGURE 4. STATION GROUPS AND AXES WITH VECTORS, DECEMBER 1976.

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TABLE 1.

WEIGHTED GROUP MEANS
TERMINAL ISLAND TREATMENT PLANT BENTHICS ** DECEMBER, 1976

                     GROUPS      1          2          3          4

  1. DEPTH                     8.2665     7.8604     7.8601     6.8531
  2. TEMPERATURE              17.2286    17.2003    17.2310    17.1613
  3. SALINITY                 32.9708    32.9635    32.9659    32.8847
  4. OXYGEN                    7.1065     6.9721     7.0289     6.5838
  5. PH                        8.1208     8.1207     8.1116     8.1324
  6. PRODUCTIVITY              2.0659     1.9471     1.6605     1.7224
  7. CHLOROPHYLL A             1.1770     1.1901     1.1383     1.4886
  8. ASSIMILATION RATIO        1.6573     1.5675     1.3688     1.3207

** ONE-WAY ANOVA FOR EACH VARIABLE * DF =    3,   32
     VARIABLE                     F
  1.  DEPTH                     0.10
  2.  TEMPERATURE               0.01
  3.  SALINITY                  0.14
  4.  OXYGEN                    0.08
  5.  PH                        0.01
  6.  PRODUCTIVITY              0.05
  7.  CHLOROPHYLL A             0.16
  8.  ASSIMILATION RATIO        0.07
```

TABLE 2.

TERMINAL ISLAND TREATMENT PLANT BENTHICS, DECEMBER 1976.

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS     ROOT           %        CUM %    CHI SQUARED       DF
  1   6.714E-02       66.9        66.9         1.88          10
  2   3.009E-02       30.0        96.9         0.86           8
  3   3.158E-03        3.1       100.0         0.09           6


COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT PLANT BENTHICS ** DECEMBER, 1976

                        AXES       1        2        3


   1. DEPTH                       3.1      0.1     40.9
   2. TEMPERATURE                10.0      3.4     24.5
   3. SALINITY                   46.4      2.1      0.6
   4. OXYGEN                     13.4      2.0     12.3
   5. PH                          4.1      2.1      0.4
   6. PRODUCTIVITY                1.7     38.1     12.0
   7. CHLOROPHYLL A               5.1      8.3      2.4
   8. ASSIMILATION RATIO         16.0     43.9      6.8
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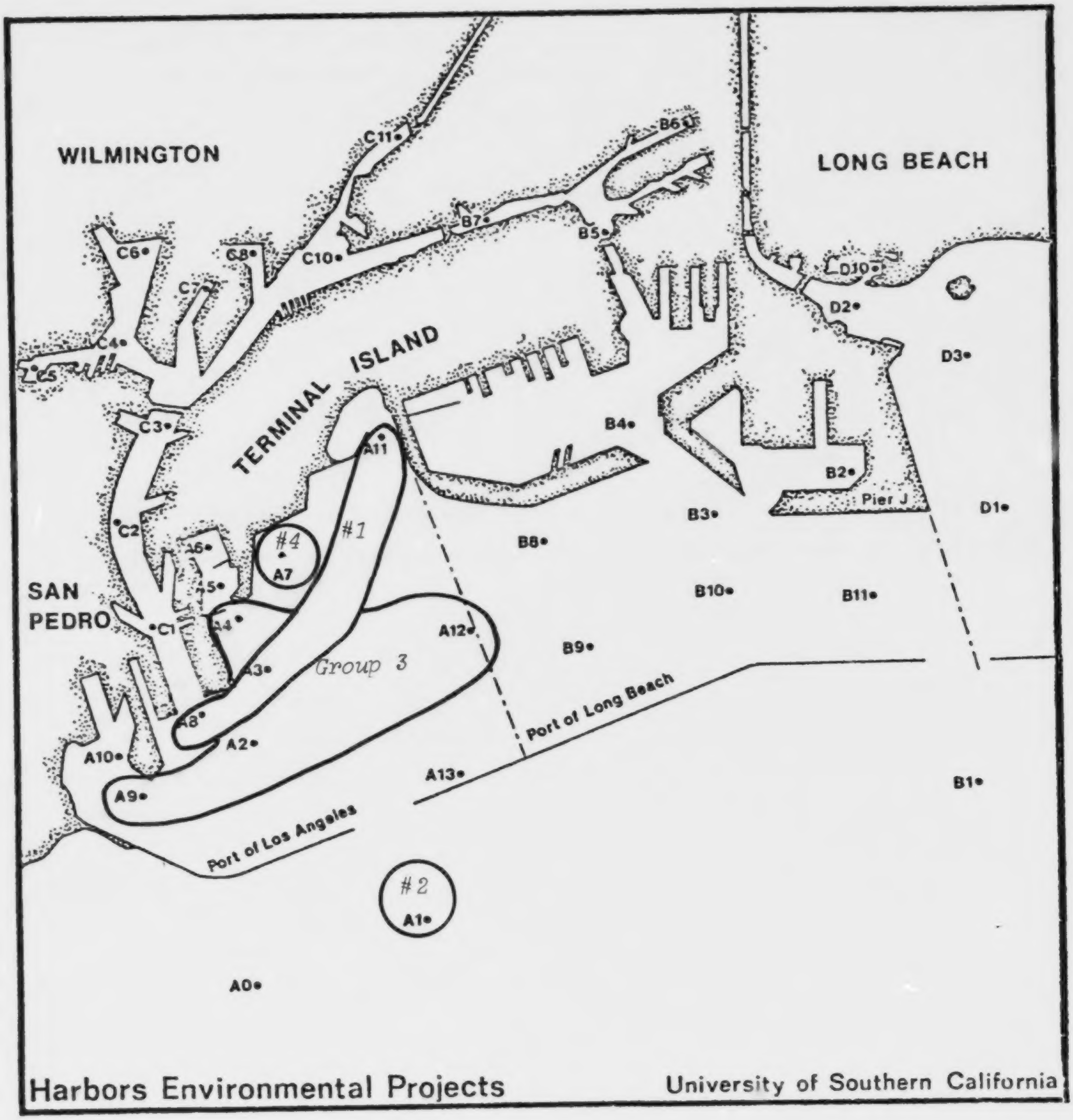
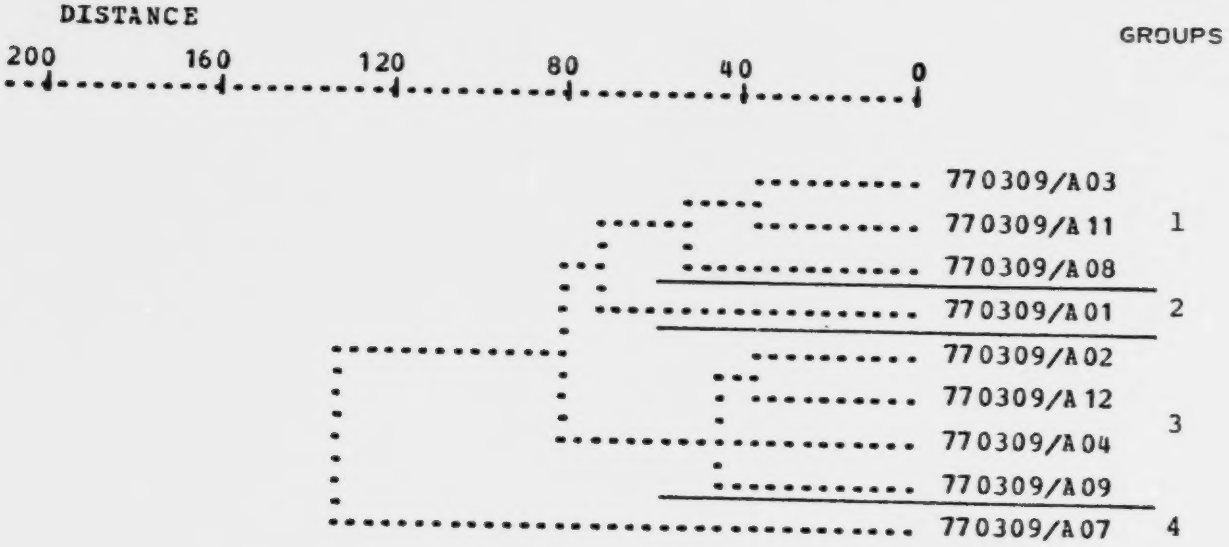


FIGURE 5. BENTHIC STATION GROUPS, MARCH 1977.

GROUP 1 - A3, A8, A11
GROUP 2 - A1
GROUP 3 - A2, A12, A4, A9
GROUP 4 - A7

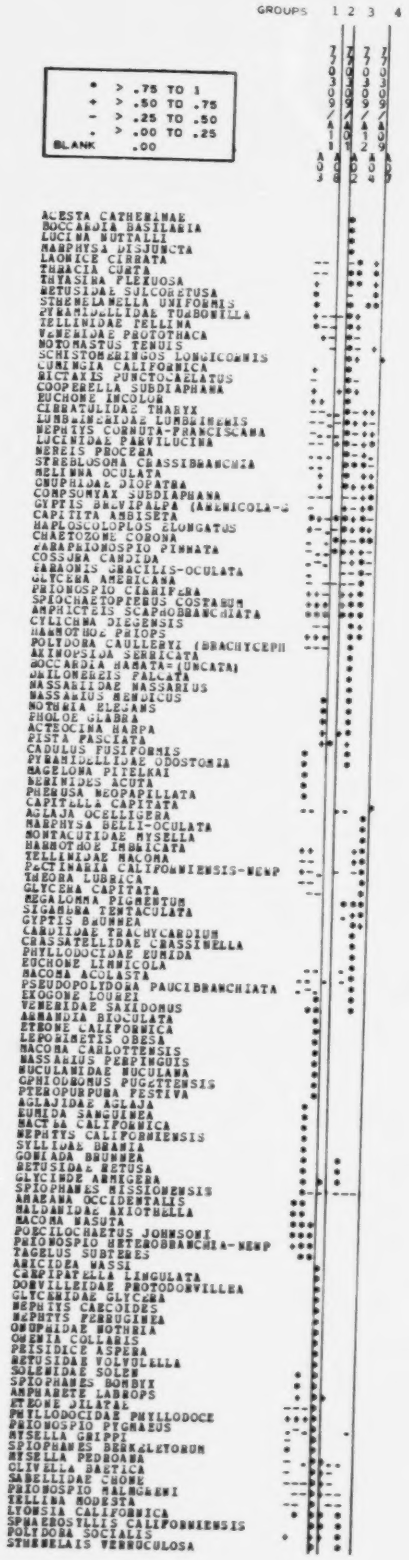
FIGURE 6.

TERMINAL ISLAND TREATMENT PLANT BENTHICS ** MARCH, 1977



TERMINAL ISLAND TREATMENT PLANT BENTHICS ** MARCH, 1977

FIGURE 7.



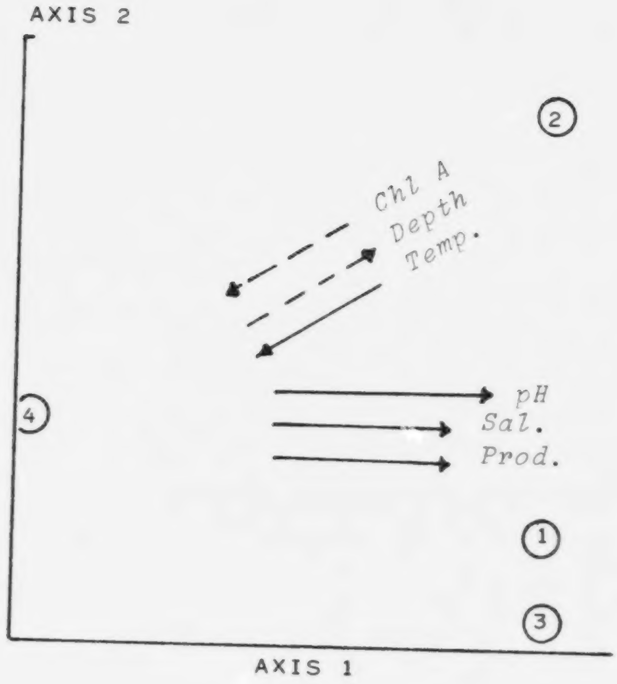


FIGURE 8. STATION GROUPS WITH AXES AND VECTORS, MARCH 1977. (DASHED LINE INDICATES VECTOR IS NOT CLEAR-CUT)

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TABLE 3.

WEIGHTED GROUP MEANS
TERMINAL ISLAND TREATMENT PLANT BENTHICS ** MARCH, 1977

                      GROUPS      1          2          3          4

  1. DEPTH                     9.9228    11.5234    10.1454     4.7286
  2. TEMPERATURE              13.3557    13.2030    13.3569    13.7475
  3. SALINITY                 31.8100    31.8091    31.8076    31.7142
  4. OXYGEN                    8.0252     7.7618     7.9892     6.4411
  5. PH                        6.1535     8.1439     8.1440     7.9077
  6. PRODUCTIVITY             13.6801    11.9738    12.8499     6.3191
  7. CHLOROPHYLL A             5.1573     4.6069     4.9025     8.2406
  8. ASSIMILATION RATIO        2.3976     2.2463     2.3498     0.8078

** ONE-WAY ANOVA FOR EACH VARIABLE * DF =     3.    32
       VARIABLE                 F
  1.   DEPTH                   0.47
  2.   TEMPERATURE             0.44
  3.   SALINITY                1.29
  4.   OXYGEN                  1.04
  5.   PH                      2.21
  6.   PRODUCTIVITY            0.16
  7.   CHLOROPHYLL A           0.55
  8.   ASSIMILATION RATIO      0.89
```

TABLE 4. TERMINAL ISLAND TREATMENT PLANT BENTHICS, MARCH 1977

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS     ROOT          %        CUM %    CHI SQUARED      DF
  1   5.211E+00      99.0       99.0        52.96         10
  2   4.002E-02       0.8       99.8         1.14          8
  3   1.131E-02       0.2      100.0         0.33          6


COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT PLANT BENTHICS ** MARCH, 1977

                          AXES       1        2        3


   1. DEPTH                         1.5     16.2     10.5
   2. TEMPERATURE                   2.8     36.8     11.6
   3. SALINITY                     12.9      0.1      4.2
   4. OXYGEN                        2.2      3.4      5.3
   5. PH                           35.9      0.5      0.5
   6. PRODUCTIVITY                 10.5     19.1     31.7
   7. CHLOROPHYLL A                29.3     10.5     18.4
   8. ASSIMILATION RATIO            5.0     13.5     17.8
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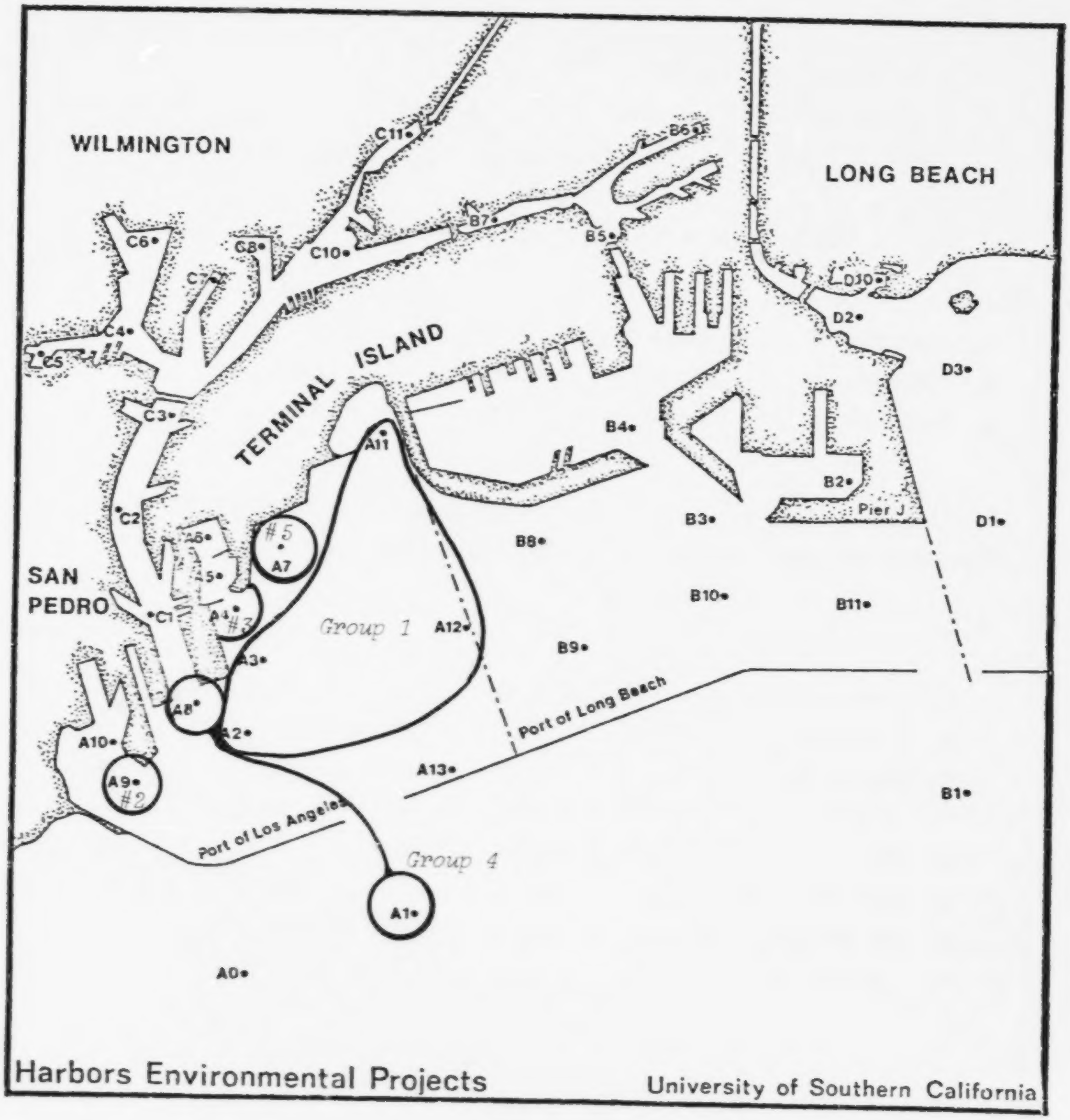
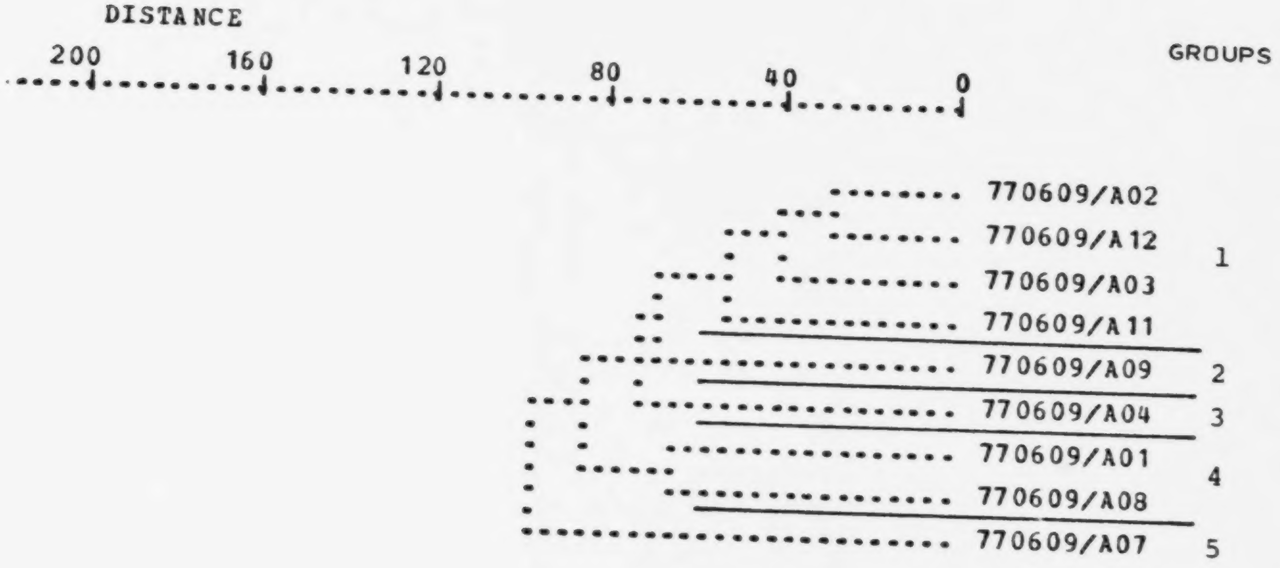


FIGURE 9. BENTHIC STATION GROUPS, JUNE 1977.

GROUP 1 - A2, A3, A11, A12
GROUP 2 - A9
GROUP 3 - A4
GROUP 4 - A1, A8
GROUP 5 - A7

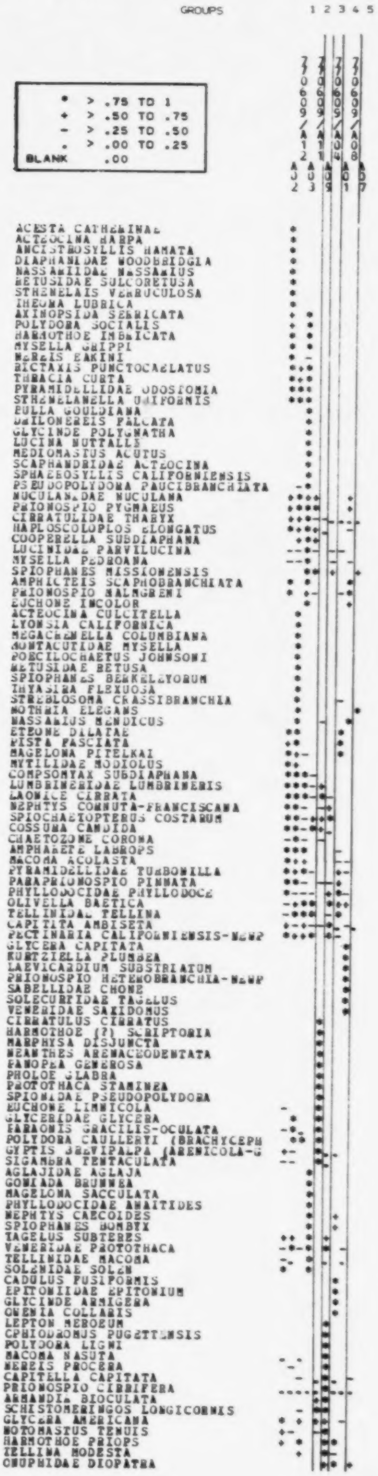
FIGURE 10.

TERMINAL ISLAND TREATMENT PLANT BENTHICS ** JUNE, 1977



TERMINAL ISLAND TREATMENT PLANT BENTHICS ** JUNE, 1977

FIGURE 11.



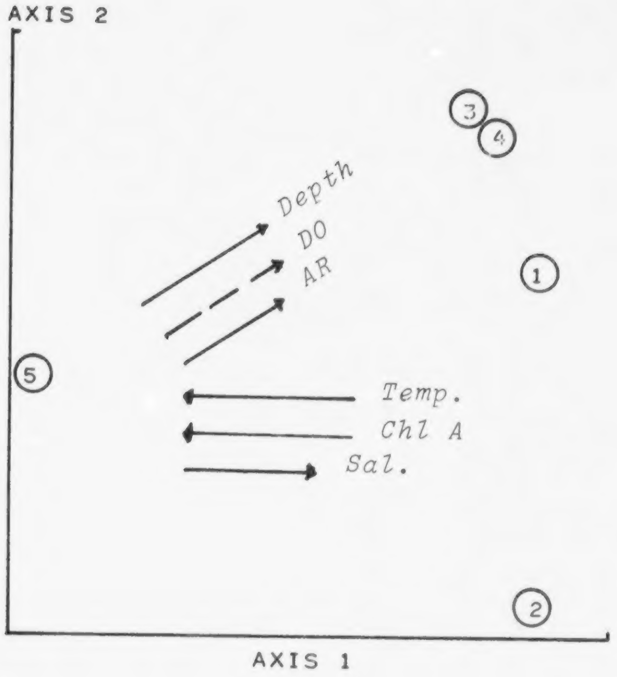


FIGURE 12. STATION GROUPS AND AXES WITH VECTORS, JUNE 1977.

TABLE 5.

WEIGHTED GROUP MEANS

TERMINAL ISLAND TREATMENT PLANT BENTHICS ** JUNE, 1977

GROUPS	1	2	3	4	5
1. DEPTH	9.2711	9.0635	8.8453	9.4506	7.3783
2. TEMPERATURE	16.7837	16.3349	17.2284	17.2248	18.1485
3. SALINITY	33.8795	33.8777	33.8613	33.8710	33.8358
4. OXYGEN	7.0976	7.0989	7.1388	7.1133	7.0629
5. PH	7.9656	7.9584	7.9457	7.9615	7.8984
6. PRODUCTIVITY	12.7388	12.3125	12.4927	12.4914	13.2675
7. CHLOROPHYLL A	1.8734	1.8833	1.9604	1.8853	2.3285
8. ASSIMILATION RATIO	7.4374	7.0730	6.8968	7.1394	5.9545

** ONE-WAY ANOVA FOR EACH VARIABLE * DF = 4, 40

VARIABLE	F
1. DEPTH	0.08
2. TEMPERATURE	0.12
3. SALINITY	0.15
4. OXYGEN	0.01
5. PH	0.18
6. PRODUCTIVITY	0.02
7. CHLOROPHYLL A	0.15
8. ASSIMILATION RATIO	0.07

TABLE 6. TERMINAL ISLAND TREATMENT PLANT BENTHICS, JUNE 1977.

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS     ROOT           %        CUM %    CHI SQUARED      DF
 1   3.025E-01        80.7       80.7         9.91          11
 2   3.821E-02        10.2       90.9         1.41           9
 3   2.836E-02         7.6       98.4         1.05           7
 4   5.902E-03         1.6      100.0         0.22           5


COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT PLANT BENTHICS ** JUNE, 1977

                        AXES       1        2        3        4

  1. DEPTH                       21.6     20.5     41.9      2.4
  2. TEMPERATURE                 11.1     50.3      2.0      0.4
  3. SALINITY                     9.0      8.2     10.1      1.5
  4. OXYGEN                       1.3     11.0      8.3      5.5
  5. PH                           7.8      2.2      6.1      0.2
  6. PRODUCTIVITY                 0.3      0.1      5.4     35.3
  7. CHLOROPHYLL A               43.7      6.4     25.7     28.6
  8. ASSIMILATION RATIO           5.3      1.3      0.6     26.2
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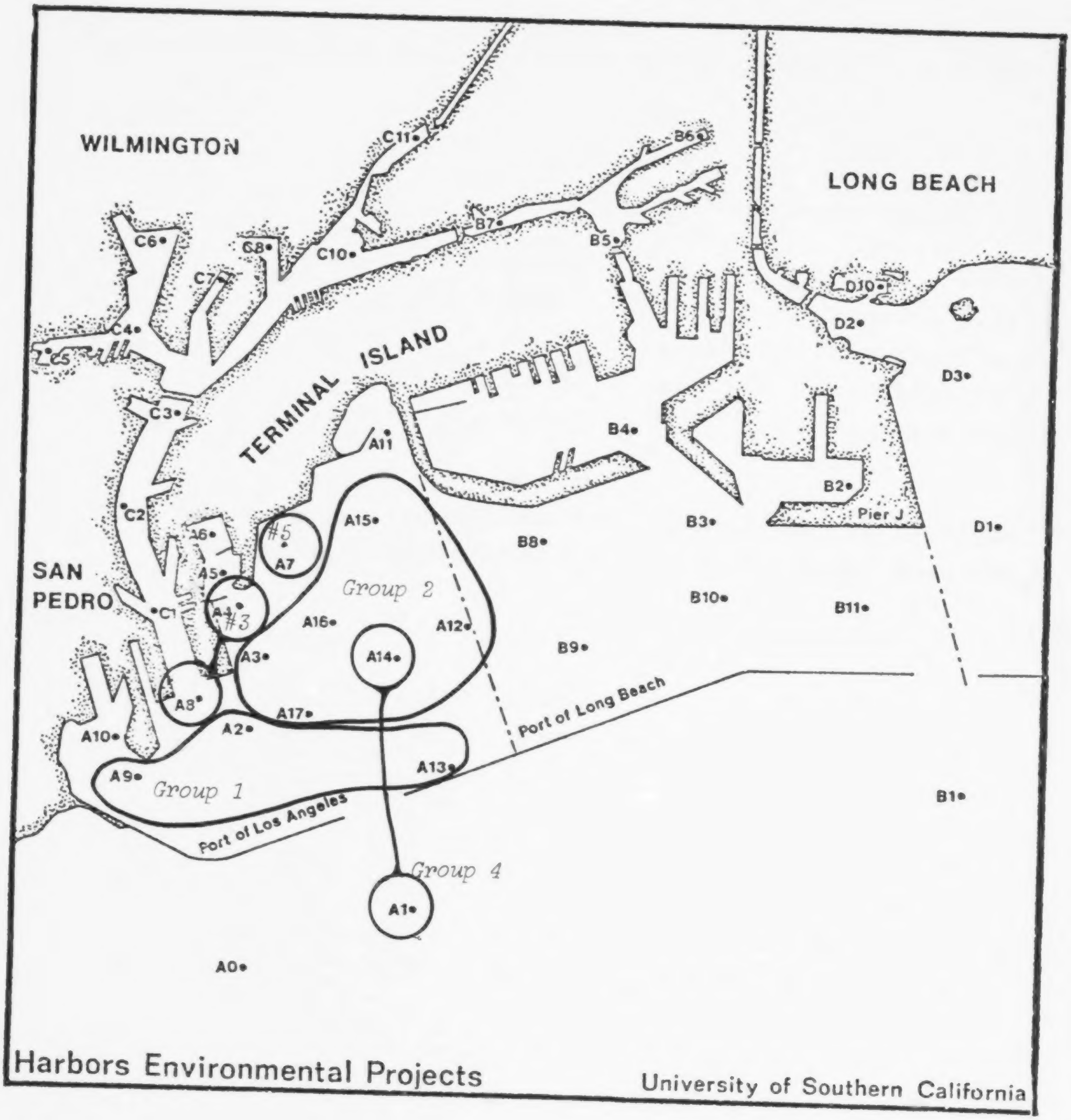
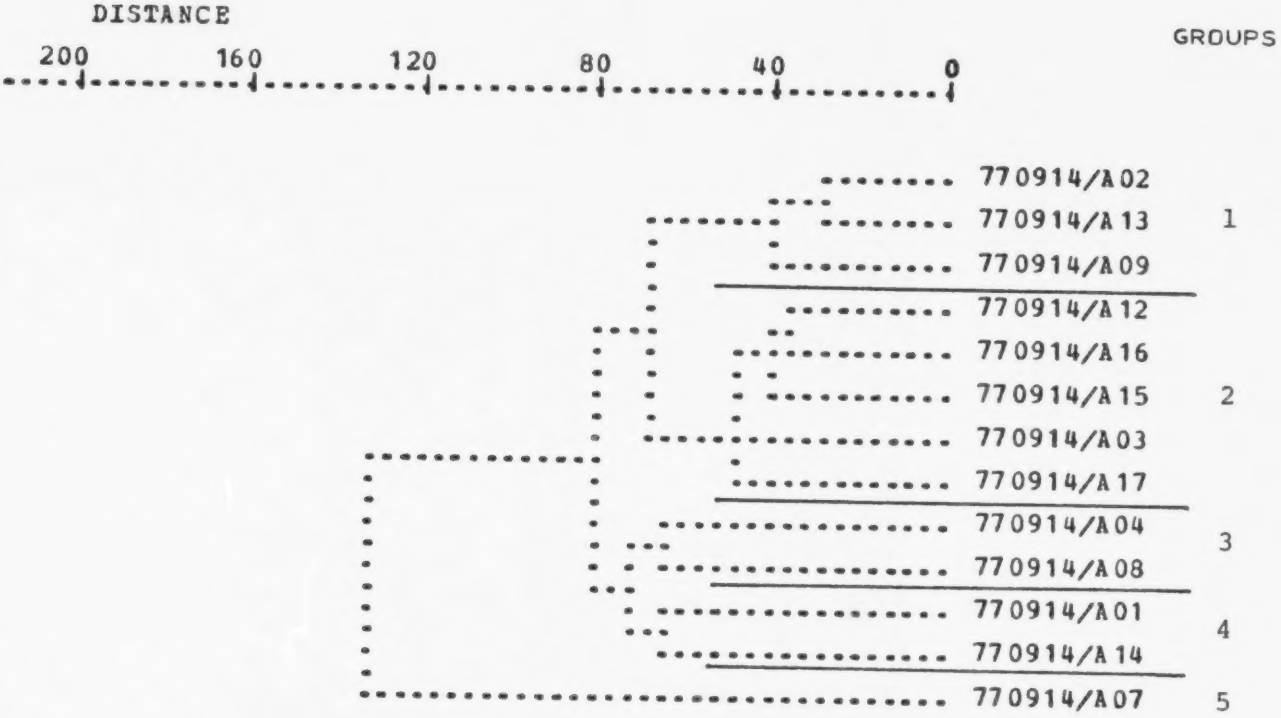


FIGURE 13. BENTHIC STATION GROUPS, SEPTEMBER 1977.

GROUP 1 - A2, A9, A13
GROUP 2 - A3, A12, A15, A16, A17
GROUP 3 - A4, A8
GROUP 4 - A1, A14
GROUP 5 - A7

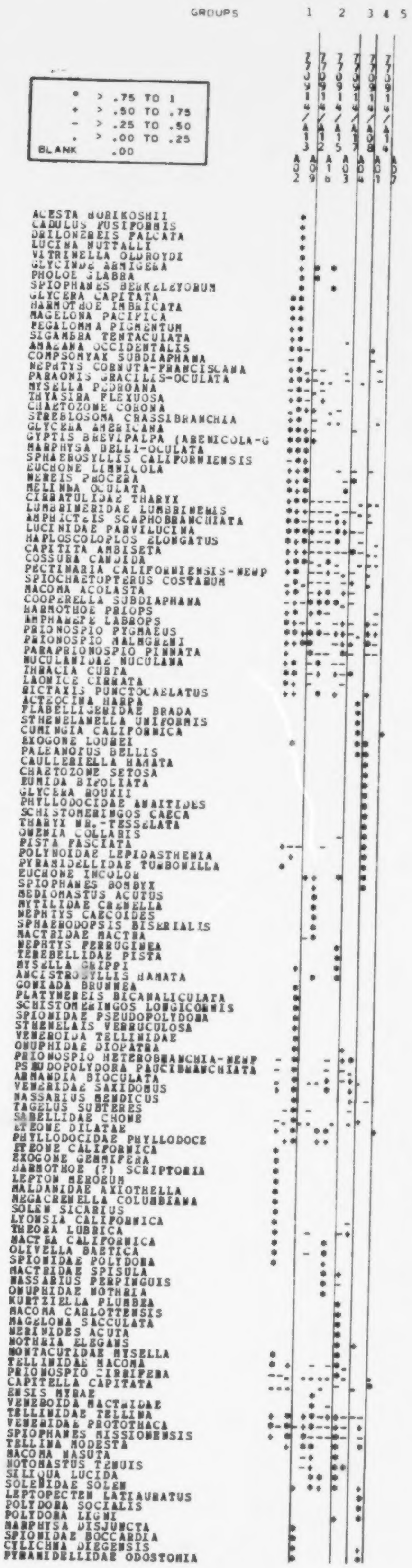
FIGURE 14.

TERMINAL ISLAND TREATMENT PLANT BENTHICS ** SEPTEMBER, 1977



TERMINAL ISLAND TREATMENT PLANT BENTHICS ** SEPTEMBER, 1977

FIGURE 15.



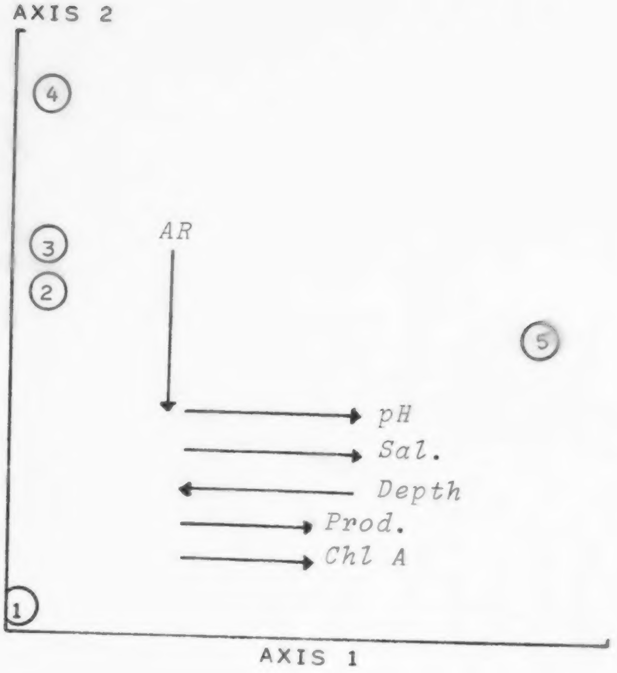


FIGURE 16. STATION GROUPS AND AXES WITH VECTORS, SEPTEMBER 1977

TABLE 7.

WEIGHTED GROUP MEANS

TERMINAL ISLAND TREATMENT PLANT BENTHICS ** SEPTEMBER, 1977

	1	2	3	4	5
1. DEPTH	9.3491	9.3005	9.2707	9.4091	8.3640
2. TEMPERATURE	16.8031	16.8212	16.8287	16.8094	16.7109
3. SALINITY	32.0921	32.0952	32.0968	32.0953	32.2248
4. OXYGEN	7.6094	7.6199	7.6104	7.6696	6.8798
5. PH	8.0228	8.0234	8.0237	8.0250	8.0335
6. PRODUCTIVITY	0.5666	0.5621	0.5617	0.5610	0.7267
7. CHLOROPHYLL A	2.2919	2.3463	2.3528	2.3515	2.5913
8. ASSIMILATION RATIO	0.3195	0.2956	0.2988	0.2889	0.2991

** ONE-WAY ANOVA FOR EACH VARIABLE * DF = 4, 60

VARIABLE	F
1. DEPTH	0.04
2. TEMPERATURE	0.02
3. SALINITY	1.03
4. OXYGEN	0.16
5. PH	0.03
6. PRODUCTIVITY	0.14
7. CHLOROPHYLL A	0.03
8. ASSIMILATION RATIO	0.02

TABLE 8. TERMINAL ISLAND TREATMENT PLANT BENTHICS, SEPTEMBER 1977

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS     ROOT            %        CUM %    CHI SQUARED      DF
  1   1.104E+00        98.8        98.8       42.76          11
  2   1.011E-02         0.9        99.7        0.58           9
  3   2.993E-03         0.3        99.9        0.17           7
  4   6.221E-04         0.1       100.0        0.04           5


COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT PLANT BENTHICS ** SEPTEMBER, 1977

                         AXES       1         2         3         4


    1. DEPTH                      31.7       1.3      13.6      46.4
    2. TEMPERATURE                 6.2      11.6      43.2      11.7
    3. SALINITY                   31.7       1.2       0.9       6.6
    4. OXYGEN                      6.7      17.0       2.6       2.8
    5. PH                         15.8      21.0      14.8      24.4
    6. PRODUCTIVITY                3.3       5.7      12.2       0.3
    7. CHLOROPHYLL A               4.5       8.3      10.7       6.5
    8. ASSIMILATION RATIO          0.0      34.0       2.2       1.4
```

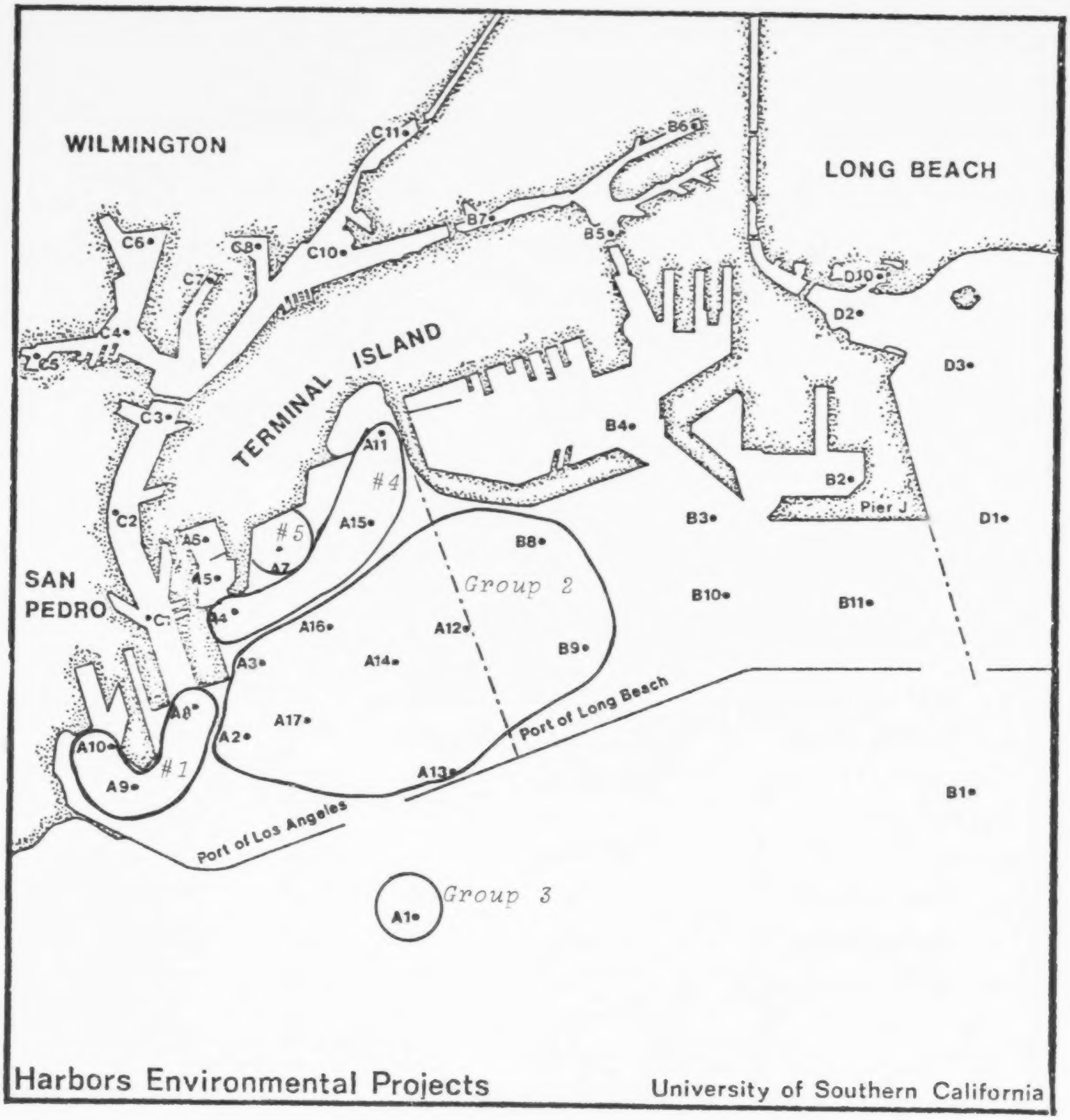


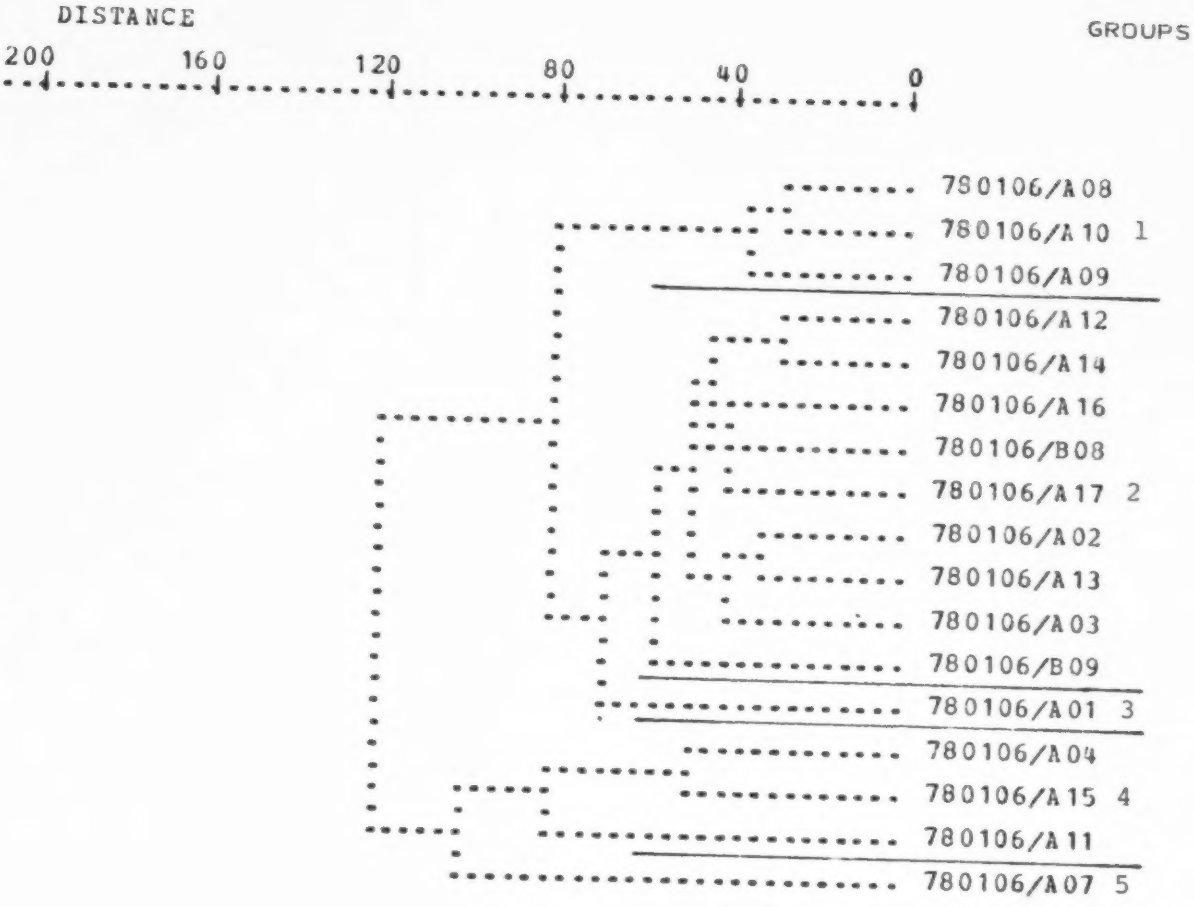
FIGURE 17. BENTHIC STATION GROUPS, JANUARY 1978.

GROUP 1 - A8, A9, A10
GROUP 2 - A2,A3, A12, A13, A14
A16, A17, B8, B9

GROUP 3 - A1
GROUP 4 - A4, A11, A15
GROUP 5 - A7

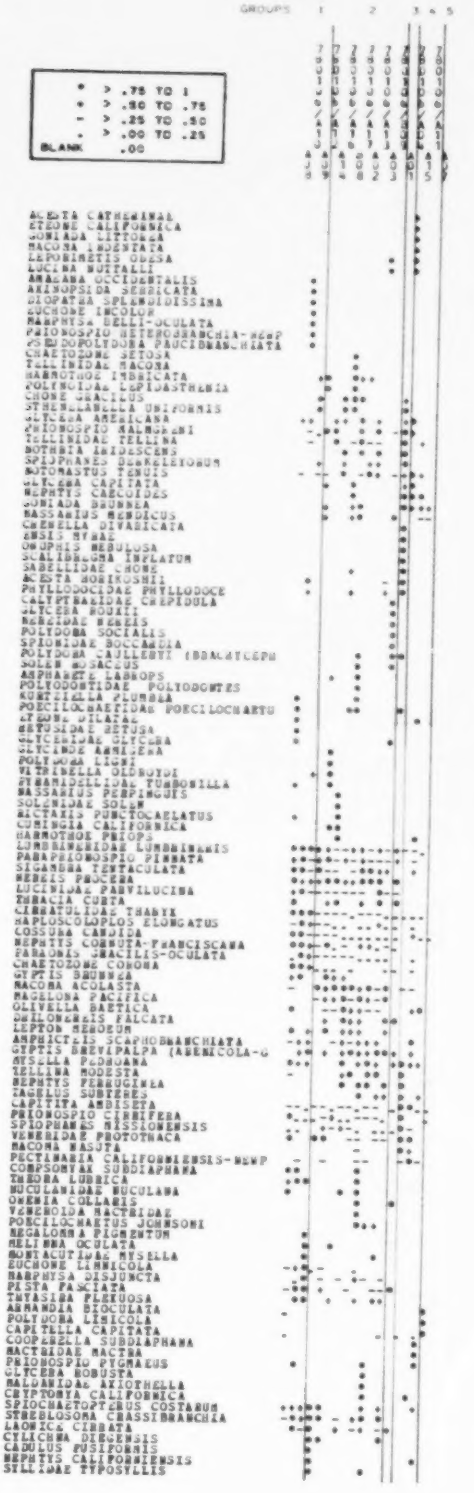
FIGURE 18.

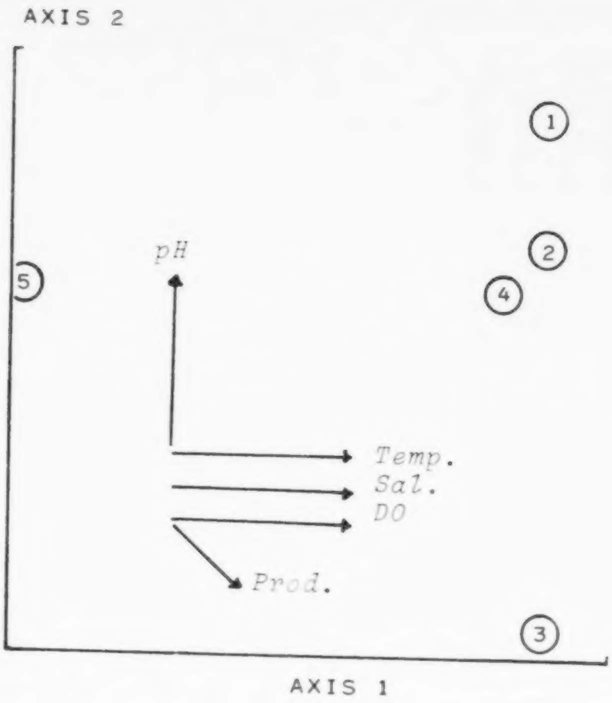
TERMINAL ISLAND TREATMENT BENTHICS ** JANUARY, 1978



TERMINAL ISLAND TREATMENT BENTHICS ** JANUARY, 1978

FIGURE 19.





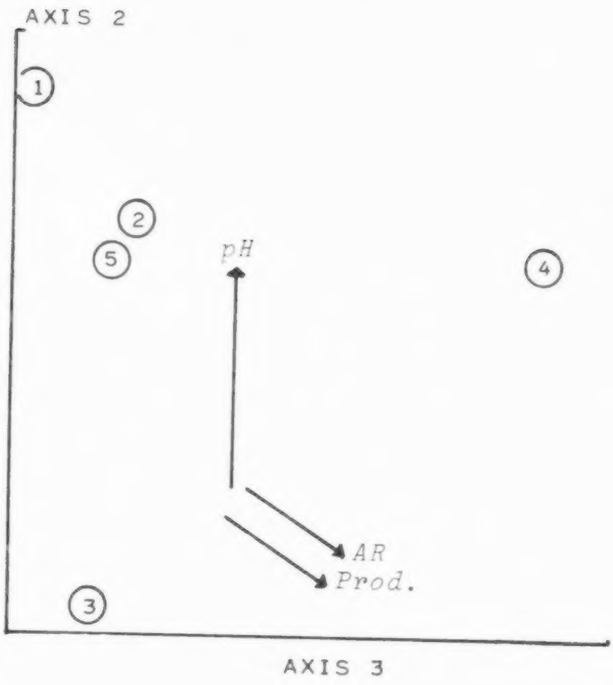


FIGURE 20. STATION GROUPS AND AXES WITH VECTORS, JANUARY 1978.

TABLE 9.

WEIGHTED GROUP MEANS

TERMINAL ISLAND TREATMENT BENTHICS ** JANUARY, 1978

GROUPS	1	2	3	4	5
1. DEPTH	10.6365	10.3837	10.3797	10.1784	7.8126
2. TEMPERATURE	16.0046	16.0003	15.9950	16.0005	15.8866
3. SALINITY *heavy rains 1½±*	27.5755	27.5688	27.5725	27.5552	27.3806
4. OXYGEN	7.3456	7.2762	7.2611	7.1817	5.9463
5. PH	8.1027	8.0690	7.9601	8.0667	8.0068
6. PRODUCTIVITY	2.1401	2.2260	2.2930	2.2682	2.1718
7. CHLOROPHYLL A	1.2220	1.2368	1.2438	1.2296	1.2114
8. ASSIMILATION RATIO	1.7256	1.7761	1.8155	1.8212	1.7752

** ONE-WAY ANOVA FOR EACH VARIABLE * DF = 4, 80

VARIABLE	F
1. DEPTH	0.39
2. TEMPERATURE	0.77
3. SALINITY	0.74
4. OXYGEN	1.37
5. PH	0.09
6. PRODUCTIVITY	0.03
7. CHLOROPHYLL A	0.01
8. ASSIMILATION RATIO	0.03

TABLE 10. TERMINAL ISLAND TREATMENT PLANT BENTHICS, JANUARY 1978

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS     ROOT            %        CUM %    CHI  SQUARED      DF
 1   2.873E-01        92.8        92.8         19.57          11
 2   1.366E-02         4.4        97.3          1.05           9
 3   7.867E-03         2.5        99.8          0.61           7
 4   6.172E-04         0.2       100.0          0.05           5

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT BENTHICS ** JANUARY, 1978
  AXES IN COLUMNS
                                 1        2        3        4

  1. DEPTH                     4.8      0.8      8.9     11.1
  2. TEMPERATURE              26.6      1.3     19.6      0.3
  3. SALINITY                 10.5      0.3     26.0      0.6
  4. OXYGEN                   56.5      0.3      6.2      0.0
  5. PH                        0.9     73.9      0.3      0.5
  6. PRODUCTIVITY              0.2      8.3     18.5     37.2
  7. CHLOROPHYLL  A            0.5      1.2      0.0     29.5
  8. ASSIMILATION RATIO        0.1     13.9     20.5     20.7
```

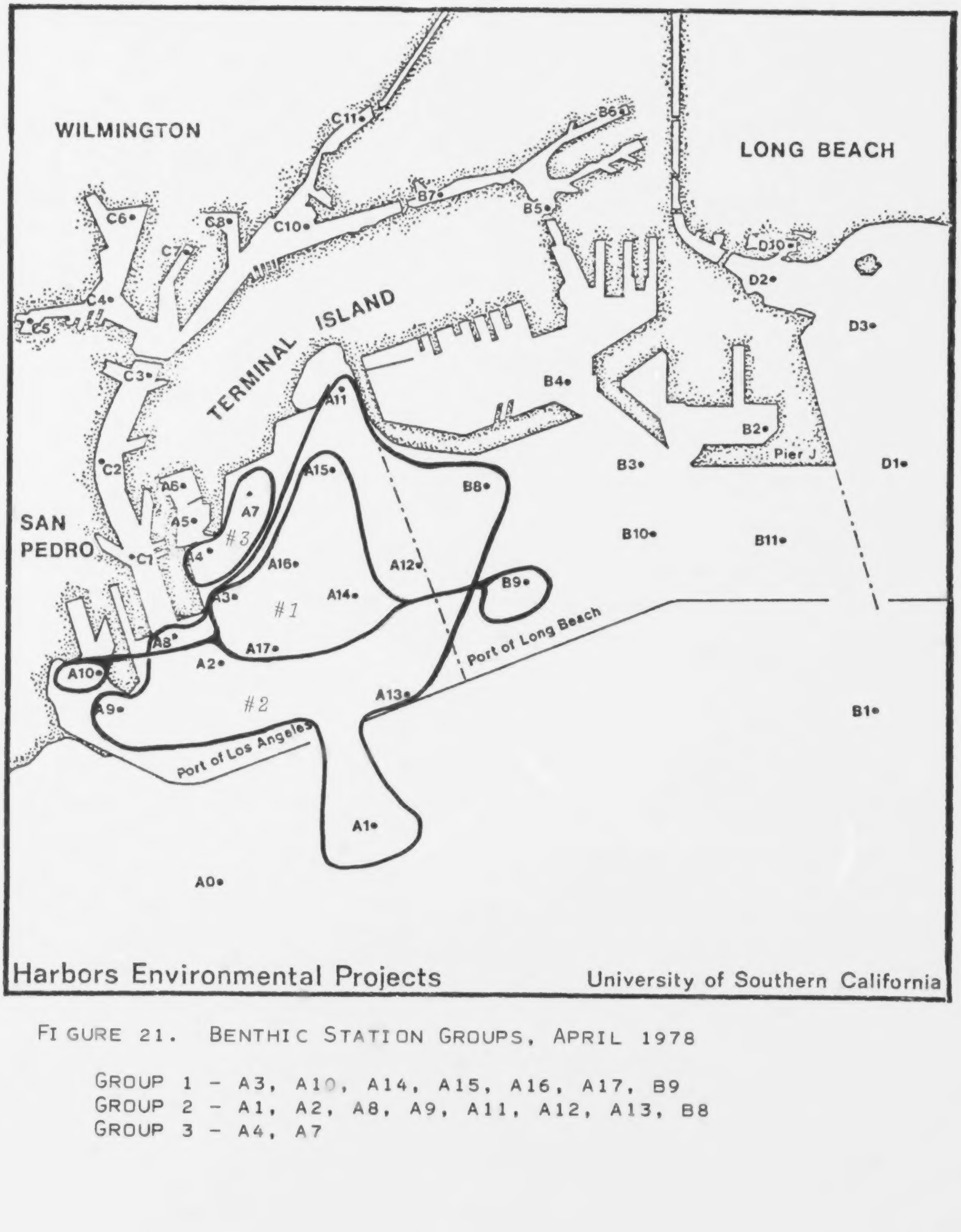
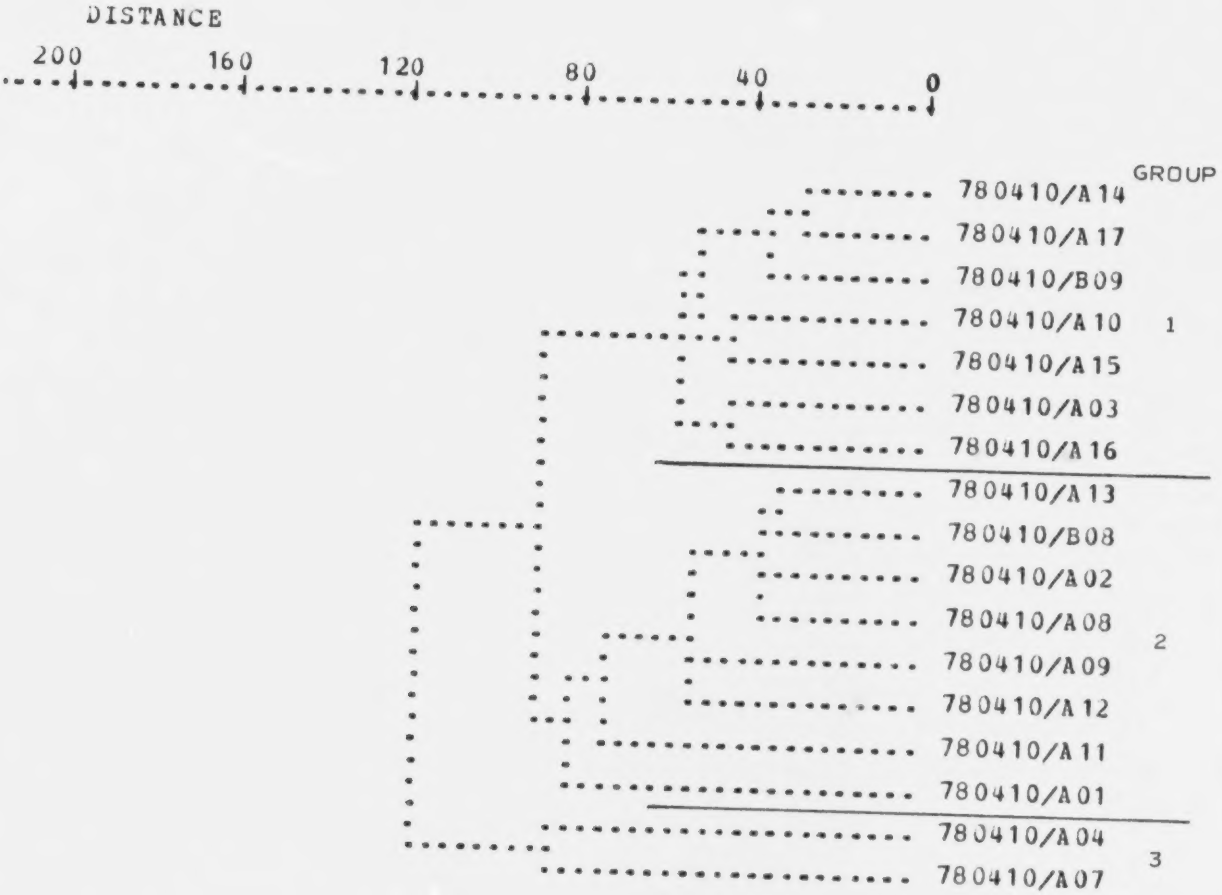


FIGURE 21. BENTHIC STATION GROUPS, APRIL 1978

GROUP 1 - A3, A10, A14, A15, A16, A17, B9
GROUP 2 - A1, A2, A8, A9, A11, A12, A13, B8
GROUP 3 - A4, A7

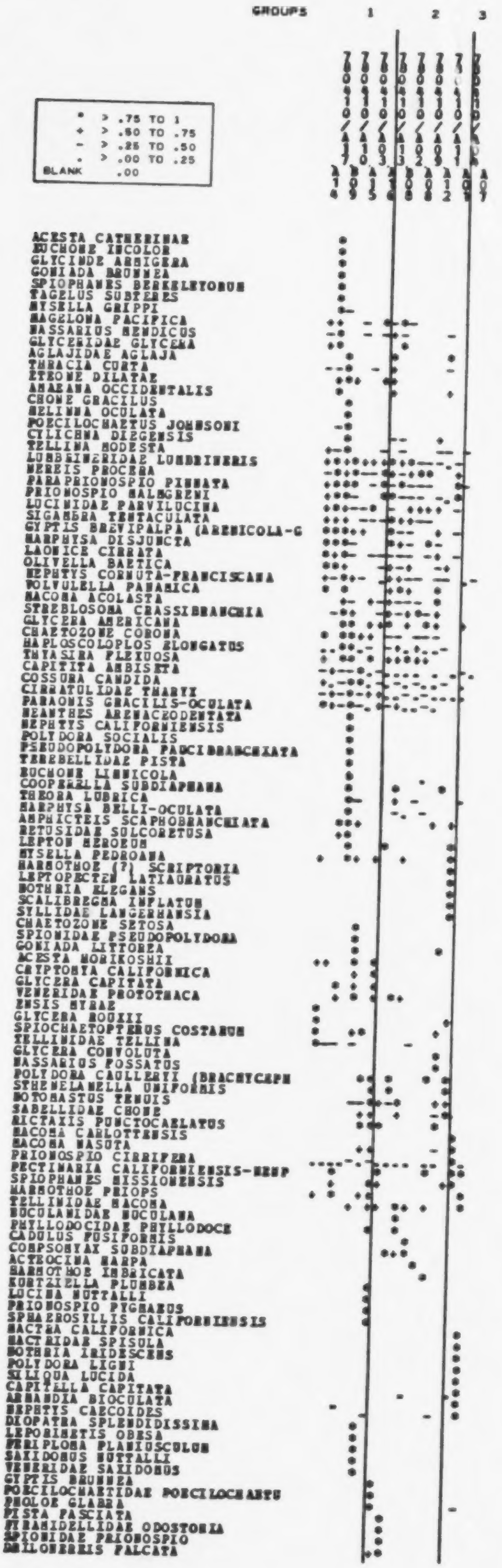
FIGURE 22.

TERMINAL ISLAND TREATMENT PLANT BENTHICS ** APRIL, 1978



TERMINAL ISLAND TREATMENT PLANT BENTHICS ** APRIL, 1978

FIGURE 23.



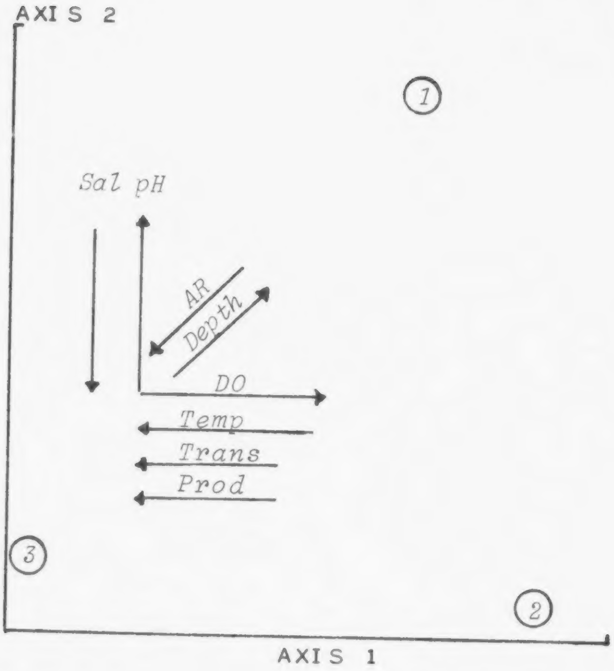


FIGURE 24. STATION GROUPS AND AXES WITH VECTORS, APRIL 1978

TABLE 11.

WEIGHTED GROUP MEANS

TERMINAL ISLAND TREATMENT PLANT BENTHICS ** APRIL, 1978

	1	2	3
1. DEPTH	10.6248	10.9074	10.0003
2. TEMPERATURE	16.1917	16.1696	16.2871
3. SALINITY	35.1184	35.1922	35.1727
4. OXYGEN	9.2477	9.3961	9.1449
5. PH	7.7294	7.7211	7.7239
6. %TRANSMITTANCE	64.7771	65.1413	63.3858
7. PRODUCTIVITY	3.3230	3.3004	3.5117
8. CHLOROPHYLL A	1.5860	1.5836	1.6050
9. ASSIMILATION RATIO	2.0889	2.0893	2.2207

** ONE-WAY ANOVA FOR EACH VARIABLE * DF = 2, 48

VARIABLE	F
1. DEPTH	0.04
2. TEMPERATURE	0.02
3. SALINITY	0.01
4. OXYGEN	0.03
5. PH	0.01
6. %TRANSMITTANCE	0.02
7. PRODUCTIVITY	0.01
8. CHLOROPHYLL A	0.00
9. ASSIMILATION RATIO	0.01

TABLE 12. TERMINAL ISLAND TREATMENT PLANT BENTHICS, APRIL 1978

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS    ROOT           %       CUM %    CHI SQUARED      DF
 1   9.223E-03       73.9      73.9         0.40         10
 2   3.257E-03       26.1     100.0         0.14          8

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **   (AXES IN COLUMNS)
TERMINAL ISLAND TREATMENT PLANT BENTHICS ** APRIL, 1978

                              1        2

 1. DEPTH                   19.7      3.7
 2. TEMPERATURE             20.7      0.4
 3. SALINITY                 0.9     25.5
 4. OXYGEN                   7.4     25.6
 5. PH                       1.7     36.4
 6. %TRANSMITTANCE          15.0      0.8
 7. PRODUCTIVITY            12.3      3.2
 8. CHLOROPHYLL A            3.4      0.0
 9. ASSIMILATION RATIO      18.9      4.3
```

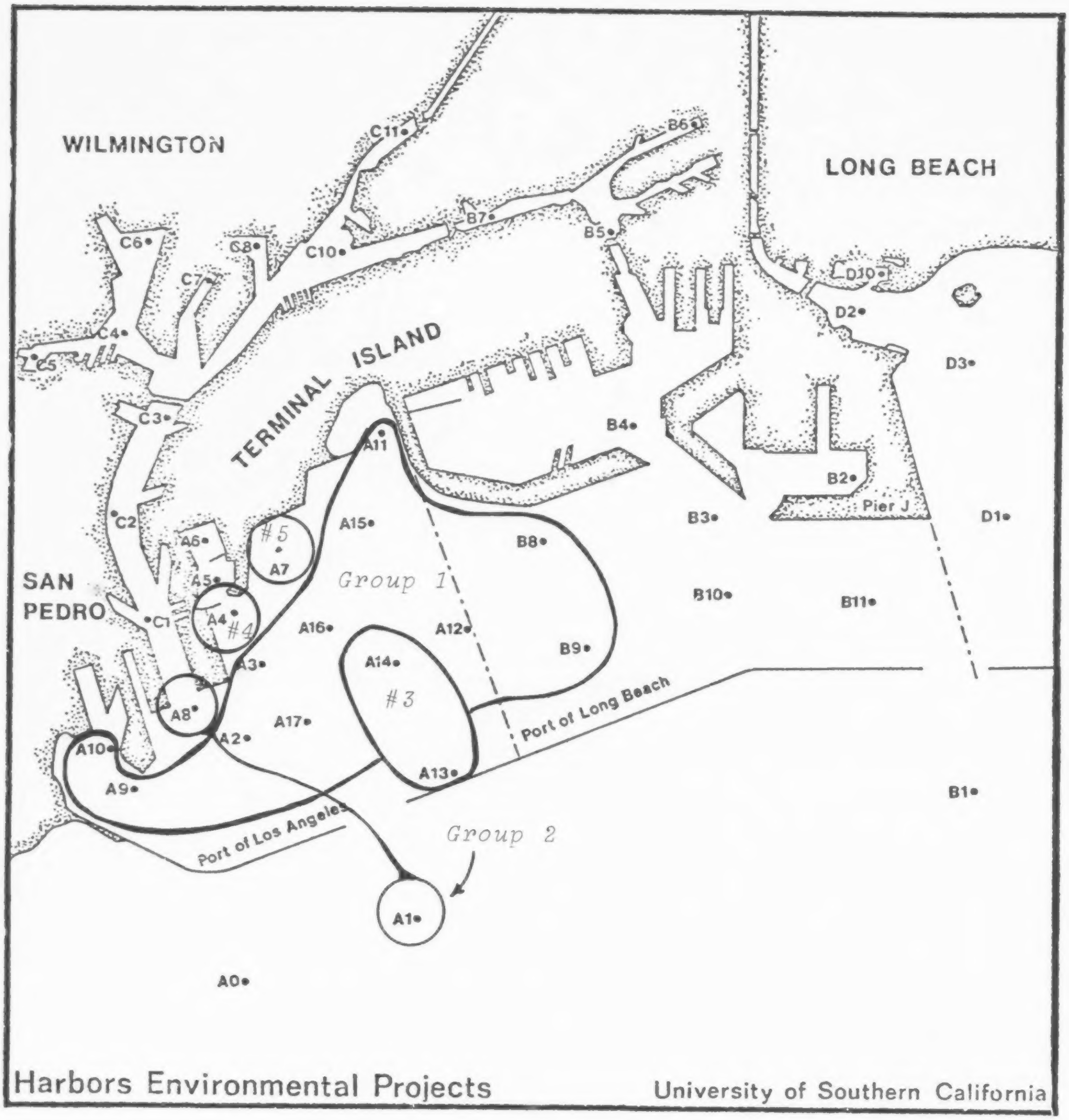
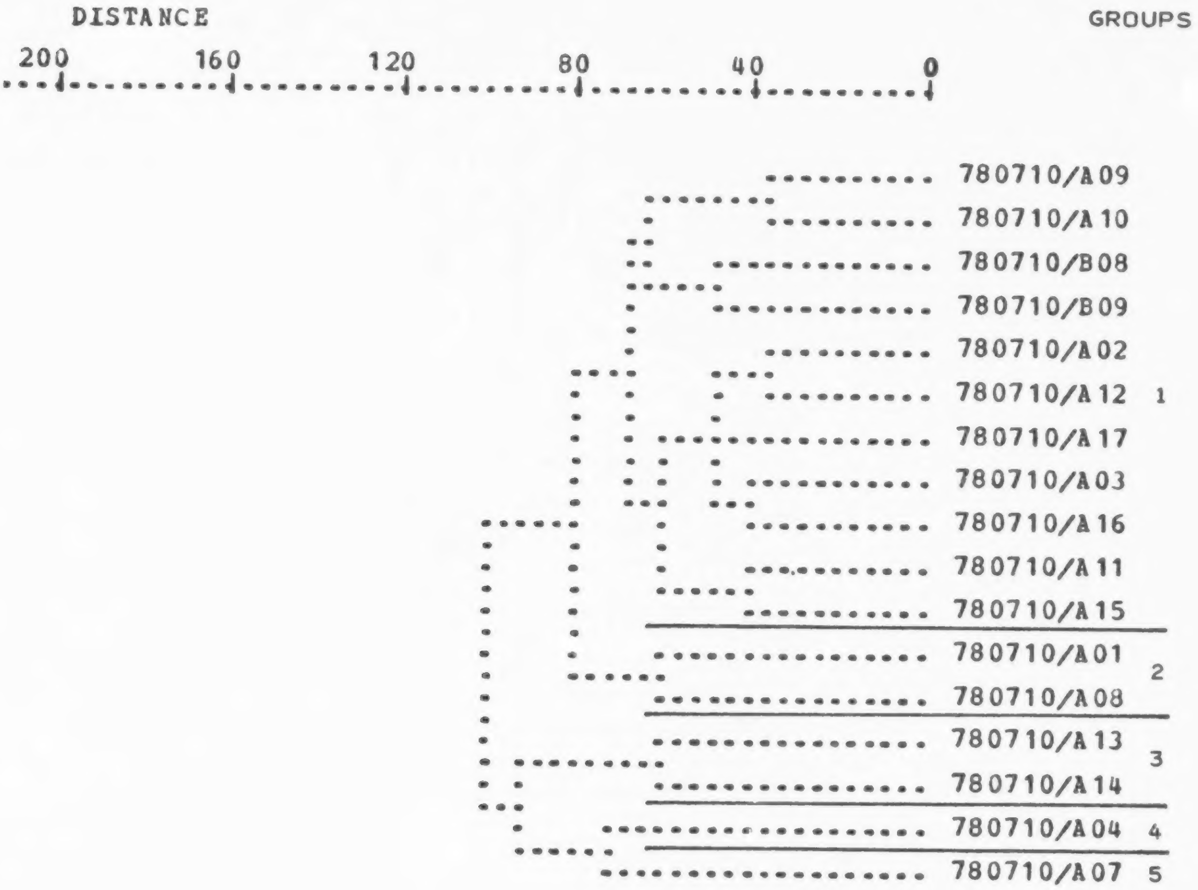


FIGURE 25. BENTHIC STATION GROUPS, JULY 1978.

GROUP 1 - A2, A3, A9, A10, A11, A12, A15, A16, A17
GROUP 2 - A1, A8
GROUP 3 - A13, A14
GROUP 4 - A4
GROUP 5 - A7

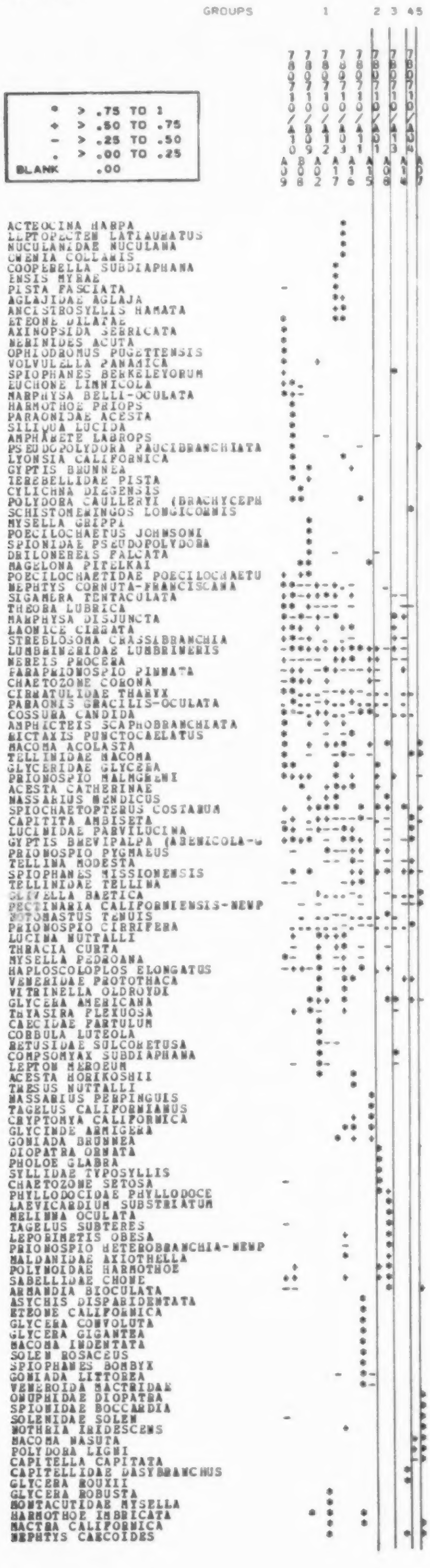
FIGURE 26.

TERMINAL ISLAND TREATMENT PLANT BENTHICS ** JULY, 1978



TERMINAL ISLAND TREATMENT PLANT BENTHICS ** JULY, 1978

FIGURE 27.



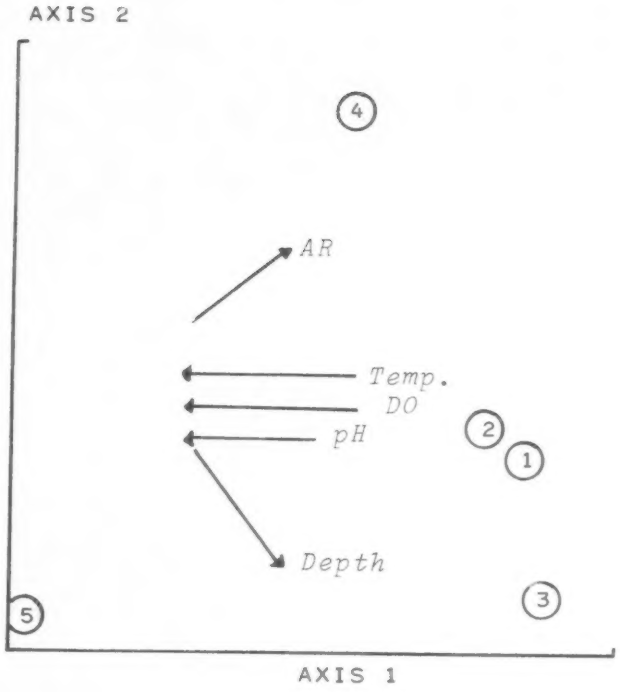


FIGURE 28. STATION GROUPS AND AXES WITH VECTORS, JULY 1978.

TABLE 13.

WEIGHTED GROUP MEANS

TERMINAL ISLAND TREATMENT PLANT BENTHICS ** JULY, 1978

GROUPS	1	2	3	4	5
1. DEPTH	10.2844	10.0290	10.6857	9.2064	8.3176
2. TEMPERATURE	12.9937	13.0890	12.8468	13.2904	13.6241
3. SALINITY	31.4894	31.4950	31.4920	31.4753	31.4324
4. OXYGEN	5.0035	5.1351	4.9645	5.1253	5.6984
5. PH	8.0487	8.0536	8.0416	8.0703	8.1102
6. PRODUCTIVITY	4.1364	4.1962	4.1943	4.7861	4.2700
7. CHLOROPHYLL A	4.6817	4.8391	4.6888	5.2902	5.2324
8. ASSIMILATION RATIO	0.9009	0.8810	0.8358	0.9046	0.8031

** ONE-WAY ANOVA FOR EACH VARIABLE * DF = 4, 80

VARIABLE	F
1. DEPTH	0.27
2. TEMPERATURE	0.22
3. SALINITY	0.18
4. OXYGEN	0.21
5. PH	0.36
6. PRODUCTIVITY	C.07
7. CHLOROPHYLL A	0.15
8. ASSIMILATION RATIO	0.05

TABLE 14. TERMINAL ISLAND TREATMENT PLANT BENTHICS, JULY 1978

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS     ROOT            %         CUM %    CHI SQUARED      DF
  1   9.329E-02        75.3        75.3         6.91         11
  2   1.860E-02        15.0        90.4         1.43          9
  3   9.237E-03         7.5        97.8         0.71          7
  4   2.699E-03         2.2       100.0         0.21          5


COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT PLANT BENTHICS ** JULY, 1978

    AXES IN COLUMNS               1        2        3        4


  1. DEPTH                      24.1      1.7      4.5      4.7
  2. TEMPERATURE                15.0     19.7      8.1      1.0
  3. SALINITY                   20.5      5.5      0.4     24.6
  4. OXYGEN                     23.1     23.8      3.2     49.0
  5. PH                         12.5      0.8      4.3      2.0
  6. PRODUCTIVITY                2.8      4.8     40.4      1.0
  7. CHLOROPHYLL A               0.9     25.6      0.3     17.0
  8. ASSIMILATION RATIO          1.1     18.0     38.8      0.8
```

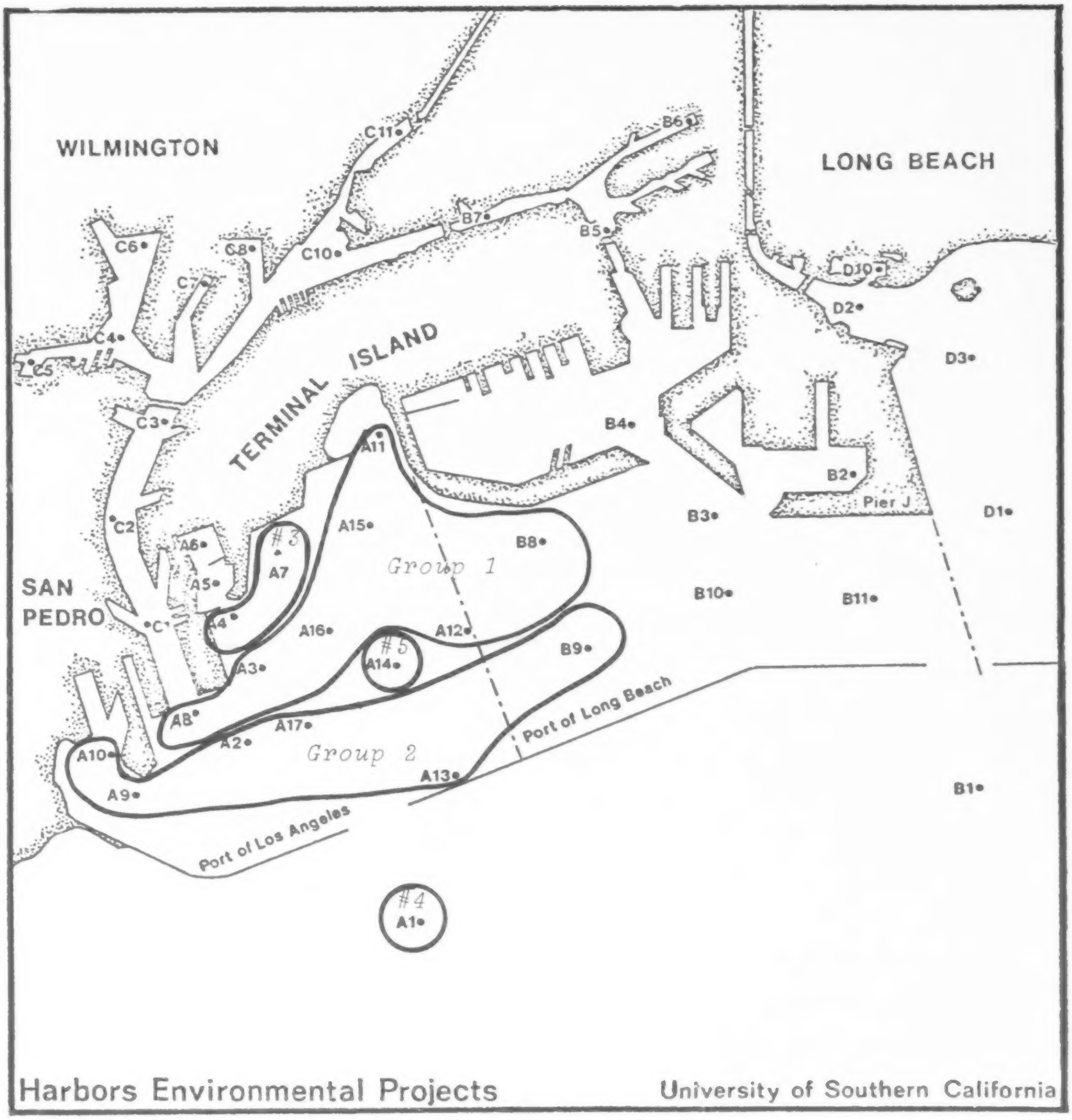
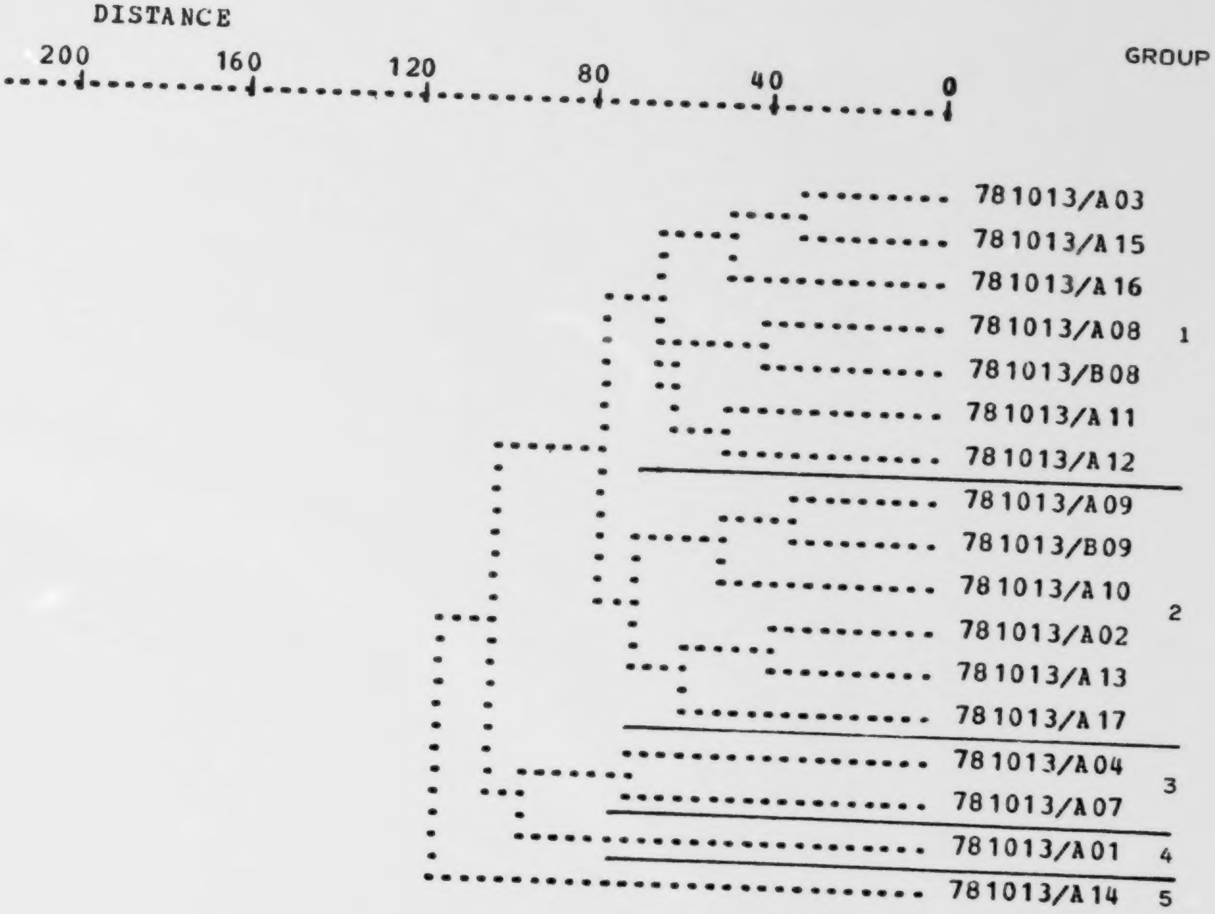


FIGURE 29. BENTHIC STATION GROUPS, OCTOBER 1978.

GROUP 1 - A3, A8, A11, A12, A15, A16, B8
GROUP 2 - A2, A9, A10, A13, A17, B9
GROUP 3 - A4, A7
GROUP 4 - A1
GROUP 5 - A14

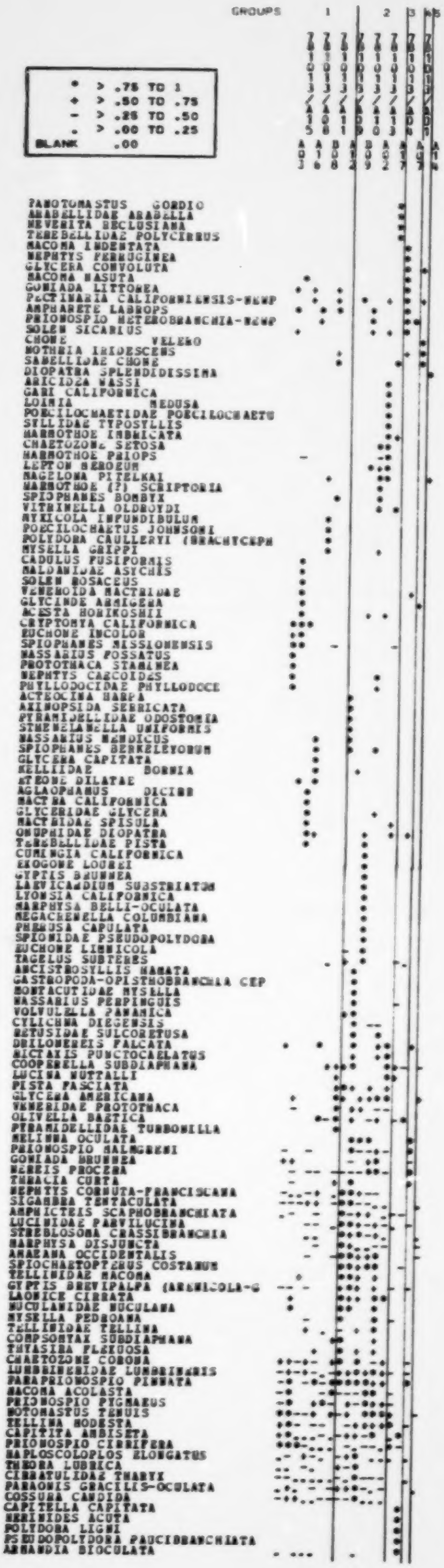
FIGURE 30

TERMINAL ISLAND TREATMENT PLANT BENTHICS ** OCTOBER, 1978



TERMINAL ISLAND TREATMENT PLANT BENTHICS ** OCTOBER, 1978

FIGURE 31.



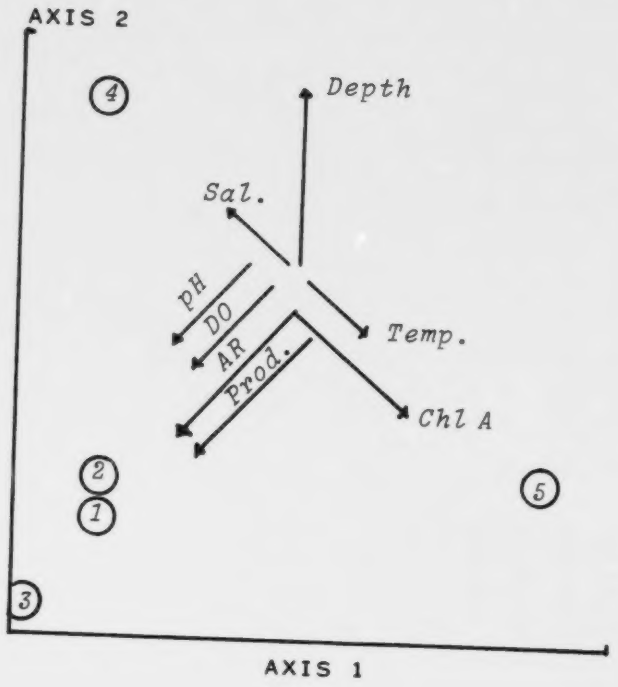


FIGURE 32. STATION GROUPS AND AXES WITH VECTORS, OCTOBER 1978.

TABLE 15.

```
WEIGHTED GROUP MEANS
TERMINAL ISLAND TREATMENT PLANT BENTHICS ** OCTOBER, 1978

    GROUPS                          1           2           3           4           5

  1. DEPTH                     11.5537     11.7040     10.9726     13.4696     11.2970
  2. TEMPERATURE               17.2055     16.9490     17.4641     16.9706     18.0490
  3. SALINITY                  31.2979     31.3049     31.2935     31.3383     31.2724
  4. OXYGEN                     6.7870      6.7799      6.8307      6.7787      6.7227
  5. PH                         8.1209      8.1187      8.1377      8.1031      8.1175
  6. PRODUCTIVITY               8.6967      8.8114      8.8250      7.9410      7.6540
  7. CHLOROPHYLL A              3.4523      3.4673      3.4304      3.2273      4.2247
  8. ASSIMILATION RATIO         2.6393      2.6685      2.6746      2.5382      2.0406

** ONE-WAY ANOVA FOR EACH VARIABLE * DF =    4.   78
      VARIABLE                    F
  1.  DEPTH                      0.20
  2.  TEMPERATURE                0.05
  3.  SALINITY                   0.17
  4.  OXYGEN                     0.00
  5.  PH                         0.04
  6.  PRODUCTIVITY               0.06
  7.  CHLOROPHYLL A              0.47
  8.  ASSIMILATION RATIO         0.11
```

TABLE 16.

```
** LATENT ROOTS AND SIGNIFICANCE TEST FOR EACH AXIS **

AXIS     ROOT              %        CUM %    CHI SQUARED      DF
 1   1.373E-01           70.5       70.5         9.72         11
 2   4.915E-02           25.2       95.8         3.62          9
 3   7.617E-03            3.9       99.7         0.57          7
 4   6.219E-04            0.3      100.0         0.05          5

COEFFICIENTS OF SEPARATE DETERMINATION (X 100/SUM(ABS VALUE))  **
TERMINAL ISLAND TREATMENT PLANT BENTHICS ** OCTOBER, 1973

   AXES IN COLUMNS               1        2        3        4

  1. DEPTH                      0.4     44.3      2.0      6.9
  2. TEMPERATURE                1.1      4.7      8.5      3.3
  3. SALINITY                   0.9      4.4      3.6     31.9
  4. OXYGEN                     0.0      0.2      8.2      7.0
  5. PH                         0.2      2.0     31.6     22.8
  6. PRODUCTIVITY              18.9     17.4     35.2     13.8
  7. CHLOROPHYLL A             41.4     17.5      1.5      3.5
  8. ASSIMILATION RATIO        36.9      9.4      9.4     10.9
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PHYTOPLANKTON GROWTH AND STIMULATION IN THE TERMINAL ISLAND TREATMENT PLANT SECONDARY WASTE PLUME

INTRODUCTION

The Terminal Island Treatment Plant (TITP) releases 10-18 million gallons of secondary treated sewage effluent into the Los Angeles Harbor daily. This series of algal bioassays was designed to assess the impact of TITP effluent on phytoplankton growth. The culture data presented here gives a clear indication of the growth response of the harbor phytoplankton community to effluent levels actually found in the harbor.

METHODS

Diatoms and dinoflagellates dominate the harbor phytoplankton community. Therefore, a mixed culture of harbor diatoms (*Skeletonema*, *Nitzschia* and naviculoid species) and a monoculture of the harbor dinoflagellate *Scrippsiella trochoidea* were used in the initial experiments of the bioassay series. The growth response of the mixed diatom culture to any given test solution was highly variable. Possibly, this was due to competitive interactions between diatom species in the spatially restricted environment of the laboratory culture. However, some differential growth response was observed. *Scrippsiella trochoidea*, an extremely slow-growing species, did show a growth response in one 7-day bioassay in February. It did not, however, show a differential growth response to any of the experiments during an 8-day June bioassay period. Therefore, use of this species was discontinued.

Dunaliella tertiolecta was selected for use in each monthly bioassay. This microflagellate is present in the harbor and it has been widely used in the past as a bioassay organism. It grows rapidly and was found to be a sensitive indicator of growth conditions.

Experimental Design

Dilution for growth tests were chosen to encompass the range of effluent concentrations found in the harbor in each sampling period. The percentages of effluent concentrations chosen conform to a logarithmic progression, with replicates prepared for each test. Six concentrations of TITP effluent (10%, 5.6%, 3.2%, 1.0%, 0.56%, and 0.1%) were tested in each period along with water from the harbor taken from over the TITP outfall and from three other stations in the Los Angeles Harbor, A7, A3, and A2, which are approximately 550m, 1525m, and 1875m, respectively, from where the effluent surfaces from the plant in a turbulent circle of water known as the "boil." Three additional samples served as controls. In addition, a dilution water sample was tested to determine minimal growth in the absence of effluent stimulation or inhibition, and a sample containing an enriched algal medium was used to assay maximal growth under optimum nutrient conditions in order to check on the health of the original inoculum culture. An Instant Ocean artificial sea water was also tested to determine minimal growth in the absence of all extraneous nutrients. However, growth in Instant Ocean was highly variable from one bioassay to another, suggesting variable nutrient content.

Preparation of Test Solutions

Each effluent concentration was prepared using TITP effluent obtained from inside the plant on the first day of each bioassay test series. The effluent was corrected for low salinity with Instant Ocean sea salts.

In the February bioassay, the effluent was diluted using ultraviolet-sterilized and filtered sea water from the Harbors Environmental Laboratory at Wilmington. Al subsequent bioassays utilized aged dilution water collected in a single batch from midchannel in the San Pedro Bight. Each assay solution was filtered through a GF/C glass filter. A 100 ml volume of this filtered solution was then transferred into each of three 250 ml Nalgene Ehrlenmeyer flasks.

Bioassay Procedures

The phytoplankton inoculum was grown in axenic culture medium for one week prior to the bioassay. After cell densities were determined, 10 ml of the healthy algal culture was inoculated into each 100 ml of test solution prepared as described above.

The culture flasks were maintained in a seawater table under constant light (approximately 40 microeinsteins/meter^2/sec.) and temperature (18.5C±5) for the 5-day bioassay period. Each flask was shaken, and its position in the table rotated daily. At 2-day intervals subsamples were removed from each flask and preserved in Lugol's solution. Cell densities were subsequently determined with a Coulter Counter.

This bioassay procedure was performed five times at bimonthly intervals in February, April, June, August, and October 1978.

RESULTS

Final Cell Yields

Representative growth curves for selected dilutions for April are given in Figure 1. Final cell concentrations for all tests of *Dunaliella tertiolecta* in the February bioassay are given in Figure 2. The laboratory seawater supply was used for dilution in the bioassay series. It was then recognized that this water alone provided nutrient enrichment. However, significantly higher cell yields were found in effluent concentrations of 1.0% or greater. The 3.2%, 5.6% and 10% dilutions were not significantly different from each other. A high yield was also produced in filtered water from station A7, located nearest to the TITP outfall boil (see Figure 3). The yield at this station was comparable to that found with the 1.0% TITP effluent. The growth response in the outfall boil tests was highly variable. Possibly, this was due to high numbers of bacteria that compete with the diatoms and dinoflagellates in this nutrient-rich medium. *Scrippsiella trochoidea* (Figure 4) and the mixed diatom culture (Figure 5) also showed increased yield at concentrations of 1.0% TITP effluent or greater. Cell yields of *S. trochoidea* were also increased in water from the four harbor stations (A2, A3, A7, and the boil itself). The highest cell numbers occurred in water from A7, the closest of the three stations to the outfall boil. For the mixed-diatom cultures, the yield in the outfall boil sample was increased, but was not significantly different from 1.0% dilutions of TITP waste in some instances and up to 10% in other tests.

The final cell yields of four subsequent bimonthly bioassays with *Dunaliella tertiolecta* are given in Figures 6 through 9. The composition of the TITP effluent is complex, with variations in nutrients and possibly unidentified inhibitors or stimulators present in varying amounts. However, the growth response observed in this series of bioassays followed a consistent pattern.

Relative to the dilution water control, cell yields were significantly increased by the addition of low concentrations of TITP effluent (0.56-3.2%). In the April, June, and August 1978 bioassays, final cell yields increased with increasing TITP concentration up to and including 10%. However, in the October bioassay final cell yield in the 10% dilution was not significantly different from the 5.6% dilution. The final cell yields in the outfall boil water were usually comparable to those from the 10% TITP solution, while average yields in the harbor station water samples usually decreased with distance from the boil. In the June bioassay, however, cell yield in the boil water sample was below that of the experimental dilution water control, and average cell yields in the other harbor station treatments increased with distance from the boil. These data suggest two possibilities: 1) The presence of an unidentified inhibitor in the harbor water diluting the effluent (if this is true, this inhibitor must have been in higher concentrations near the boil than near the outer harbor stations A3 and A2); or 2) The formation of an inhibitor resulting from an interaction between components of the effluent and substances in the waters of the harbor. It is not possible to distinguish definitely between these two alternatives on the basis of the information available. However, the TITP plant malfunctioned during the period in question, allowing raw wastes to escape. Chlorination was also heavy in that period.

Specific Growth Rates

Final cell yields are useful as a means of comparison among the tests. In this series of bioassays, high initial cell concentrations were used to insure detection of any stimulatory or inhibitory effect. Therefore, the final cell densities were much higher than those that would normally be found in the harbor. Initial cell concentrations also varied somewhat from one bimonthly bioassay to another.

In order to make comparisons between bioassays and the growth of the natural phytoplankton populations, specific growth rates were calculated. Specific growth rate (r) is defined as the rate of population increase per day.

$$r = \frac{\log e \frac{Nt}{No}}{t}$$

where Nt = cell density at day t

No = cell density at day 0

t = total time interval in days

Average specific growth rates for all preparations in five bioassays are given in Table 1.

The February bioassay differed from the four subsequent bioassays in that the initial phytoplankton concentration was much lower and the bioassay ran for seven days rather than eight. Each of these factors would contribute to higher r values. Maximum short-term r values were observed during the June bioassay in 10% TITP ($r = .67$) and in water from the boil ($r = .68$).

The bioassays were conducted under constant, fluorescent illumination of 40 microeinsteins/m^2/sec (0.0132 langleys/min.). This is equivalent to approximately 2 percent of full midday sunlight. Natural phytoplankton communities encounter comparable light intensities within the upper five meters depth in the harbor (Kremer, personal communication). Smayda (1973), however, found that the diatom *Skeletonema costatum* reached light saturationtion of 0.15 langleys/min., a light intensity approximately 10 times greater. Specific growth rates also vary with temperature. Under optimum light conditions in culture *D. tertiolecta* reached a maximum specific growth rate of 1.23 at 18°C (Eppley, 1972). This value is approximately double the maximum short-term growth rates in our experiments. Therefore, it is probable that light limited the maximum specific growth rates obtained here, and that r values would have been greater if light levels were increased.

Natural phytoplankton from oligotrophic waters off southern California showed r values of 0.17-0.28 at 20°C in simulated *in situ* conditions. The maximum r expected for optimum conditions was 1.5. In the nutrient-rich waters of the Peru Current, r averaged 0.46 at 17-20°C, about half of the r expected under optimum light conditions (Eppley, 1972). Even in those relatively clear waters, light limitation appears to decrease r. Thus, the light levels used in the bioassay appear to reflect actual conditions in the harbor environment.

Nutrients

Marine phytoplankton require a variety of nutrients for growth and reproduction. Phytoplankton growth is believed to be limited by whichever factor is present in minimal quantity. Nitrogen, phosphorus and silicon are potentially limiting to phytoplankton growth because they are not always present in excess. Nitrogen and phosphorus are utilized in the synthesis of organic materials at a ratio of 15N:1P. If the phytoplankton in the harbor assimilate nitrogen and phosphate in approximately this ratio, phosphate is very unlikely to become limiting (see harbor nutrient levels in Table 2). Nitrogen has been shown to be the most important nutrient that limits phytoplankton growth in marine systems (Riley and Chester, 1971). According to Sverdrup, *et al.* (1942), inorganic nitrogen is present in natural sea waters as nitrate (.1-43 µg-at/l NO_3), nitrite (.01-3.5 µg-at/l NO_2) and ammonia (.35-3.5 µg-at/l NH_3). Nitrate is usually the most abundant and stable source of nitrogen in oligotrophic (nutrient-poor) waters. Ammonia is the energetically more efficient N form and is preferentially absorbed when available (Harvey, 1955). This form (NH_3) may become the more important N source at times (see Thomas, 1966). Secondary waste treatment usually elevates nitrate and nitrite production, but may decrease ammonia (Dunstan and Menzel, 1971).

Uptake of nitrate is believed to be suppressed when NH_3-N exceeds 1.0 µg-at/l (Eppley *et al.*, 1969). Until September 1978 NH_3-N levels in the TITP effluent exceeded 150 µg-at/l. Therefore NH_3 probably provided the N utilized in phytoplankton growth. The total inorganic nitrogen content of the TITP effluent during bioassay months is given in Table 2. These data indicate that nitrogen levels in the 10% TITP bioassay treatment ranged from 120 to 200 µg-at N/l. Nitrogen enrichment alone could account for the increased growth rates in the TITP treatment. Since September 1978 the total inorganic N levels have not greatly changed. However, secondary treatment is now converting most NH_3-N to the NO_3 form. Where nitrogen and phosphorus are present in excess, other factors may become limiting, such as: iron, manganese, copper, molybdenum, boron, vanadium, zinc, and, for diatoms, silicon; all are required in small quantities and may potentially become limiting.

CONCLUSIONS

Impact on the Harbor Phytoplankton Community

The introduction of TITP effluent into the harbor can be viewed as local perturbation of the phytoplankton community. In order to predict the spatial and temporal extent of the perturbation, we have applied the concept of critical length (Kierstead and Slobodkin, 1953; Steele and Mullin, 1977). The critical length of a unique patch of water is defined as the minimal size necessary for that patch to maintain itself despite the dispersive process of mixing. The critical length is given by:

$$LC = \pi\sqrt{\frac{K}{r}}$$

where K is the coefficient of horizontal eddy diffusion and
r is the specific growth rate characteristic of phytoplankton in the patch.

This model incorporates factors reflecting the unique chemical, biological (r) and physical (K) characteristics of the patch.

The specific growth rates characteristic of phytoplankton in the TITP plume have been empirically determined by bioassay. When current speeds are known, diffusion coefficients for a point source are given the following equation from Foxworthy and Kneeling (1969):

$$K = \frac{us^2}{2x}$$

where u = average current speed
s^2 = the mean variance of the waste concentration distribution in a given coordinate direction as a function of distance (x) along a plume discharged from a point source.

Tidal circulation within the harbor is weak. The currents in the area of the TITP plume are primarily wind-generated, averaging .1-.2 knots or approximately 5-10 cm/sec (Robinson and Porath, 1974; McAnally, 1975). Using Foxworthy and Kneeling values for s^2 and substituting these current speeds into the above equation, we have generated diffusion coefficients ranging in magnitude from 2×10^2 to 2×10^3. These values can then be used in the critical length model.

Increased specific growth rates were detected at effluent concentration of 1.0% or greater. Using 1% TITP to define the limits of a patch, estimates of critical length have been computed below.

			Critical Length LC = $\frac{K}{r}$ (meters)	
	r(day^{-1})	r(hr^{-1})	where K = 2 x 10^2	K = 2 x 10^3
1% mean r	.28	.01	444	1405
1% max. r	.55	.02	314	993

According to this model, when the 1 percent dilution patch exceeds the critical length, the effects of the effluent plume will persist over significant scales of time (several days) and distance (several kilometers). If harbor nutrient levels are used as an index of dilution, the 1 percent dilution level falls between station A7 and A3, 550 meters and 1525 meters from the TITP boil, respectively (see Table 2 and Figure 10). This inference is strengthened by the bioassay findings that phytoplankton growth in water from station A7 was comparable to that of the 1 percent treatment (see Figures 8 and 9). Thus, the dimensions of the 1 percent plume do at times exceed the critical lengths generated by the model, and the effluent patch can be expected to persist for several days, enough time to produce a local increase in the phytoplankton crop. Through continued dispersive losses, this locally persistent patch would contribute to elevated phytoplankton densities in the harbor.

Bioassay tests using various cultures of phytoplankton were conducted at bimonthly intervals during 1978 to determine the effect of the waste waters on growth rates. Concentrations of 0.1 to 10% waste water from Terminal Island Treatment Plant were tested and surface waters from four stations extending from the boil to the breakwater were sampled for comparison.

The general pattern found was one of increasing growth rate with increasing concentrations of waste water. The 1 percent concentration appeared to be the level above which the growth rate increased most sharply. Goldman and Stanley (1974) found that *Dunaliella tertiolecta* did not increase in biomass in culture at concentrations of more than 20 percent sewage.

Station A7, about 525 meters from the boil, showed growth rates comparable to those found in the 1 percent solution. Using measured nutrient concentration as an index of dilution, the 2 perc[illegible]level would lie between station A7 and station A3, about [illegible]25 meters from the boil. This suggests that in 1978 the zone of enhanced phytoplankton productivity extends only to about 500 to 1500 meters from the boil.

LITERATURE CITED See Section VI

Figure 1

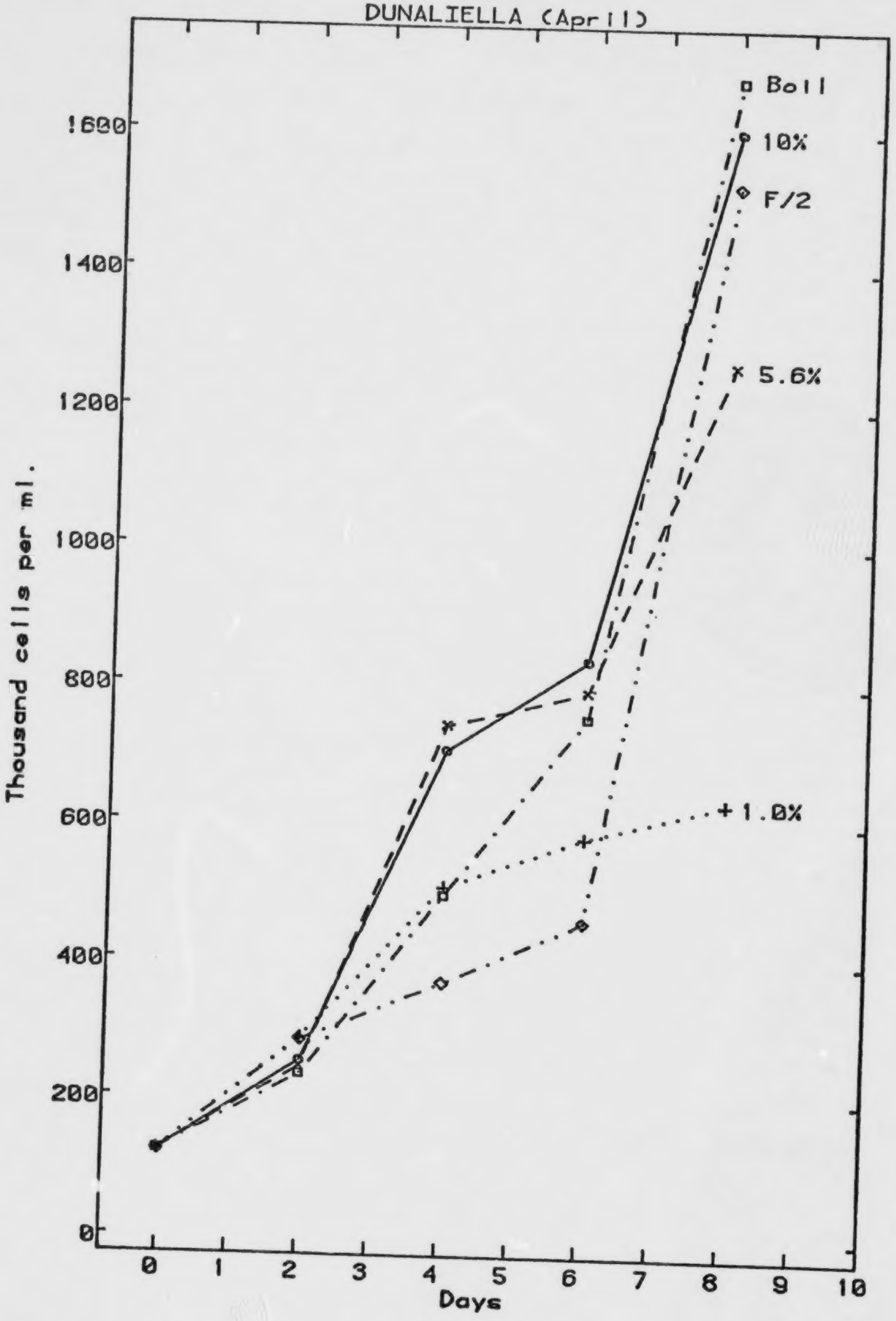
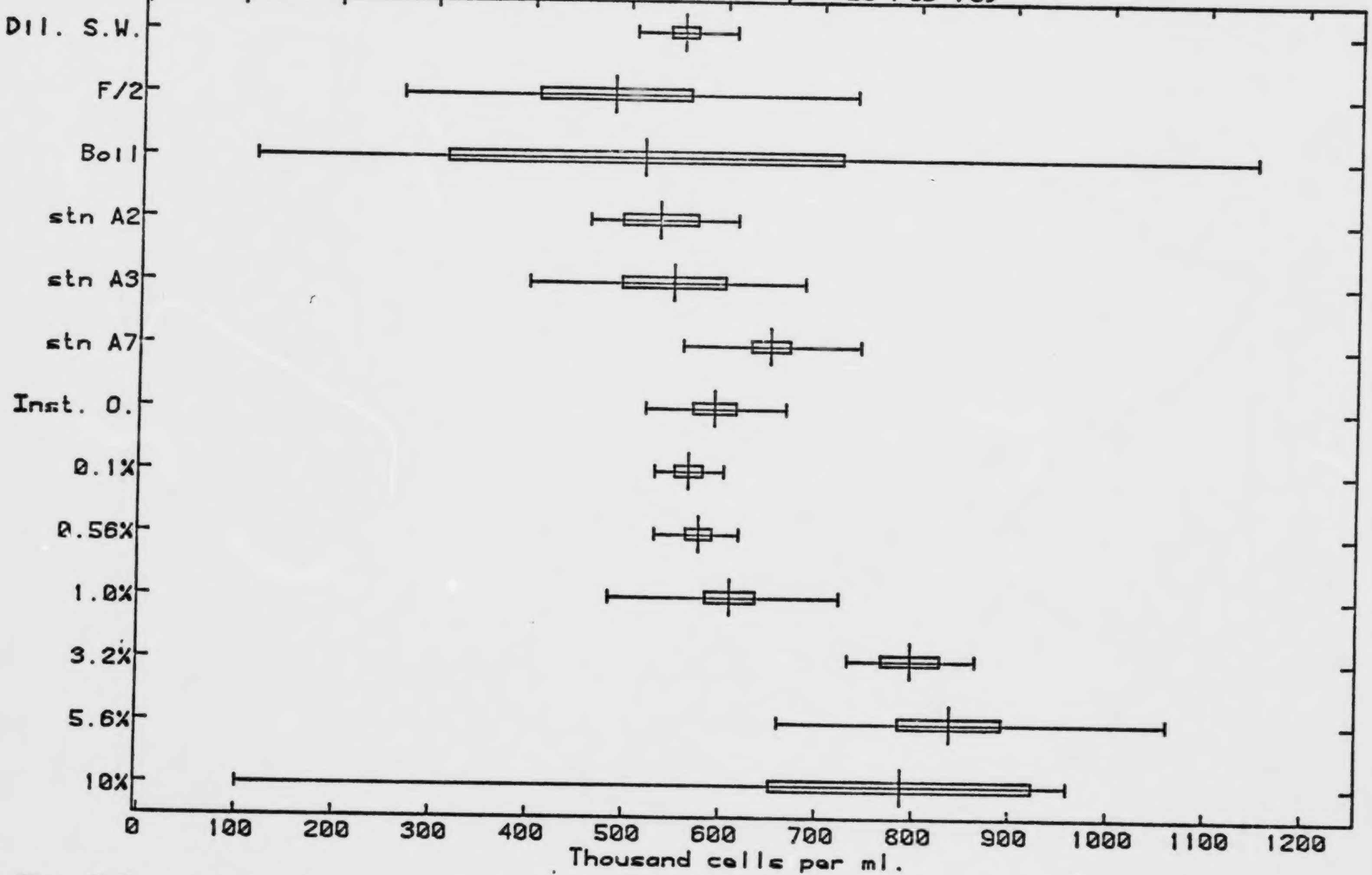
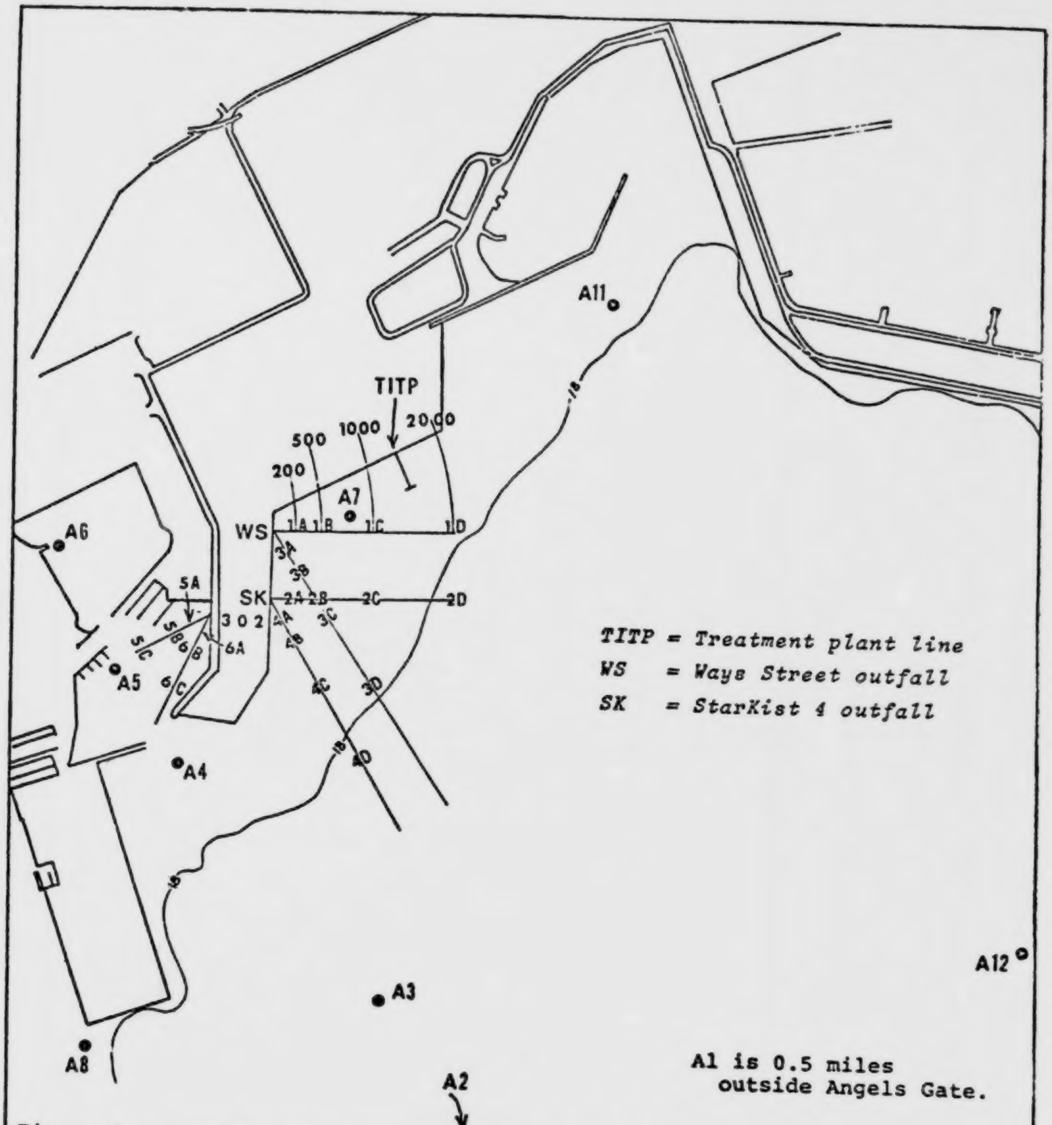

DUNALIELLA (April)
Thousand cells per ml.
0
200
400
600
800
1000
1200
1400
1600
Days
0
1
2
3
4
5
6
7
8
9
10
Boil
10%
F/2
5.6%
+ 1.0%

Figure 2

DUNALIELLA (7th Day - 20 Feb 78)



* The difference is significant (by anova, $P< 0.001$); Range & mean ± 2 S.E. are shown.



TITP = *Treatment plant line*
WS = *Ways Street outfall*
SK = *StarKist 4 outfall*

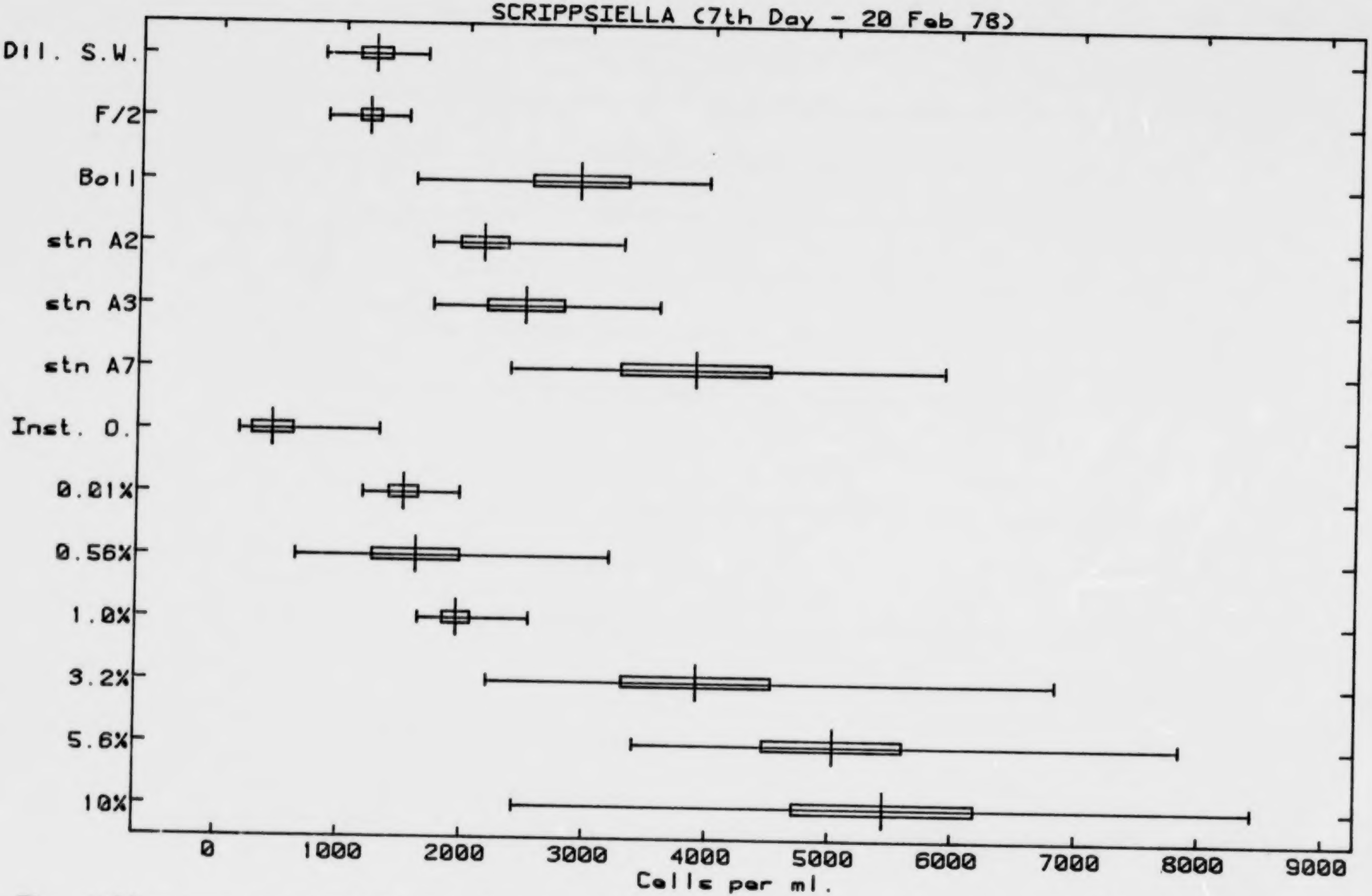
A1 is 0.5 miles outside Angels Gate.

Figure 3. Water Quality Monitoring Stations in Effluent Area.

1000 ft

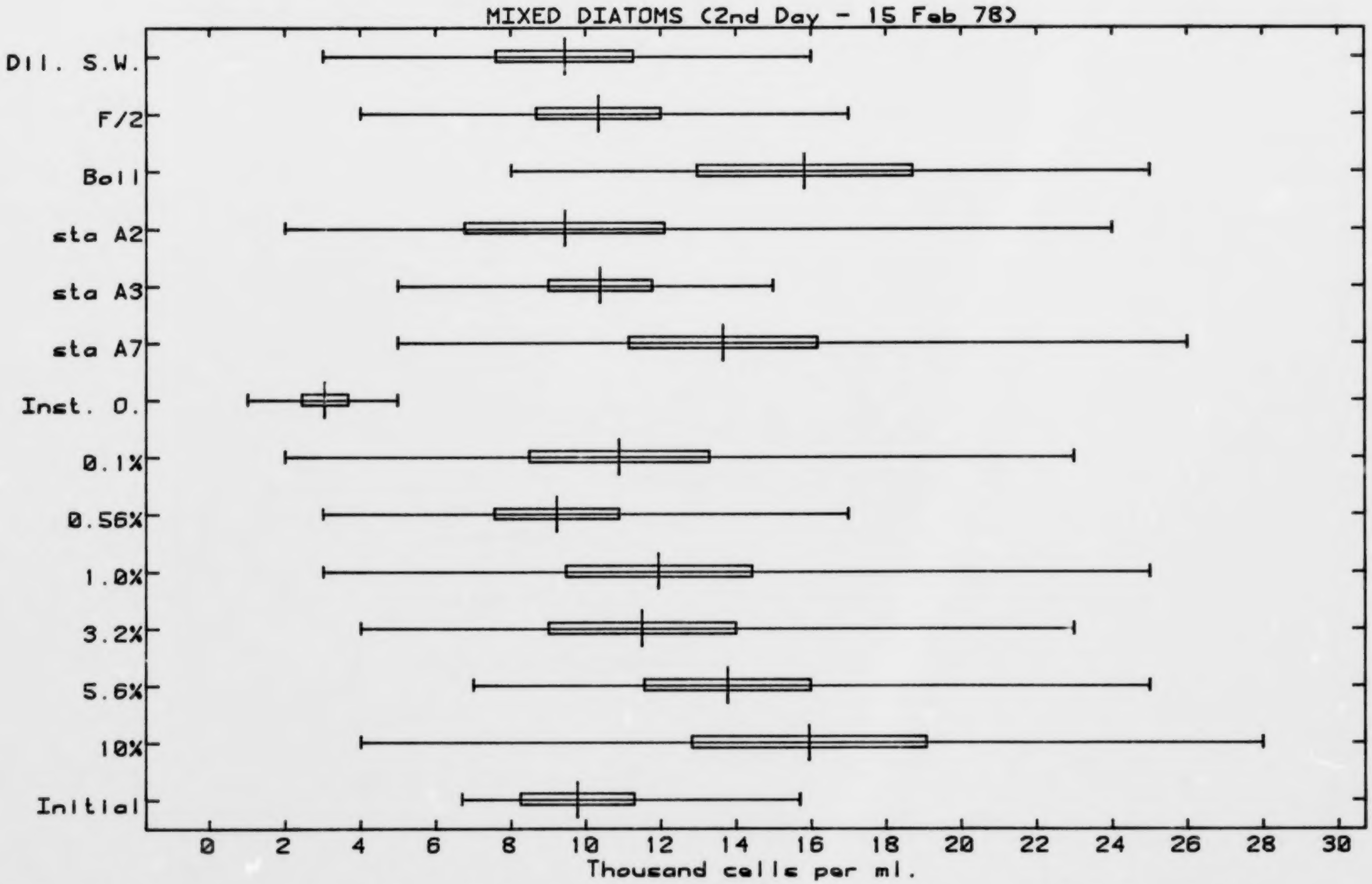
Figure 4

SCRIPPSIELLA (7th Day - 20 Feb 78)



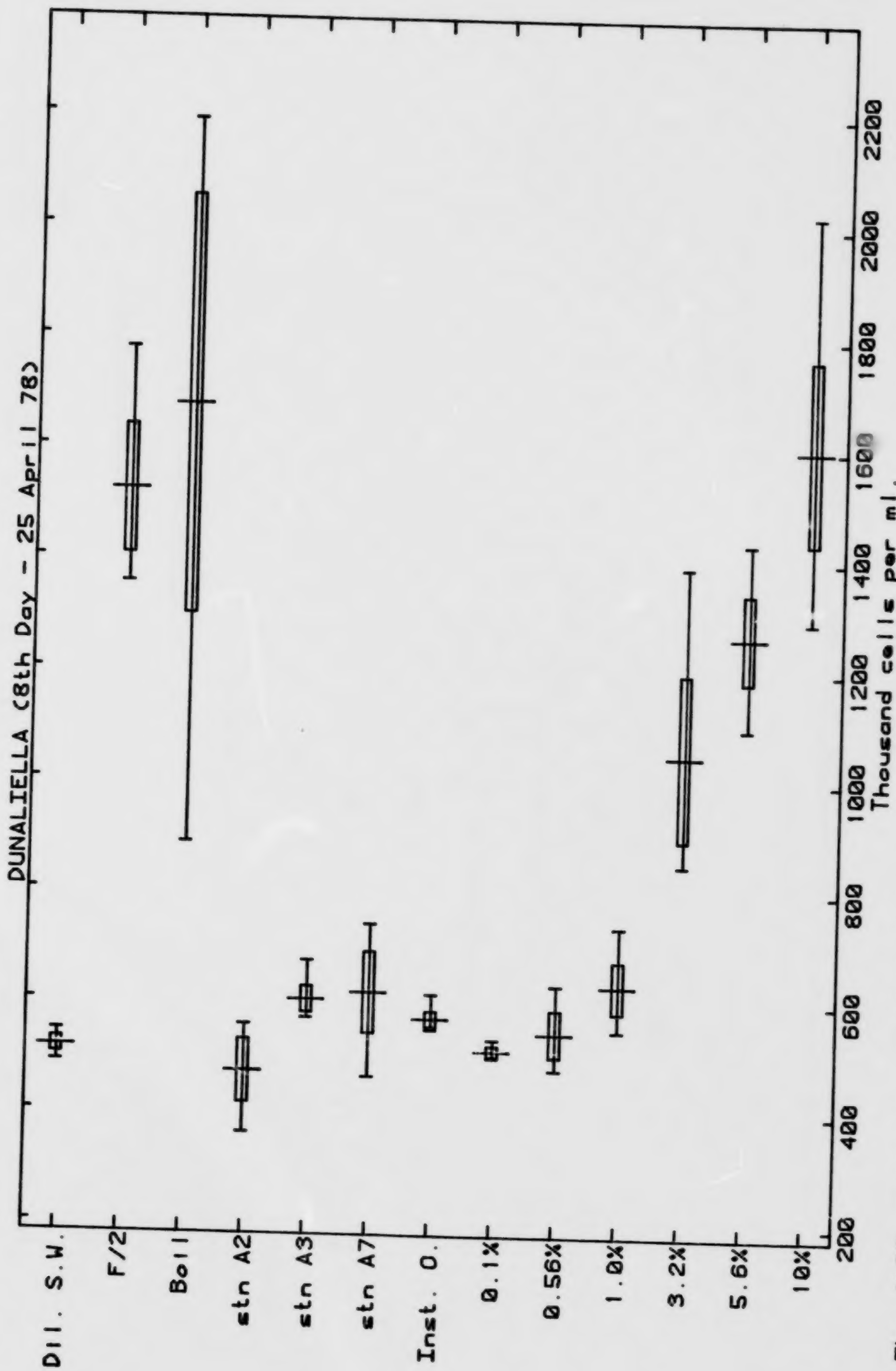
* The difference is significant (by anova, $P < 0.001$); Range & mean ± 2 S.E. are shown.

Figure 5



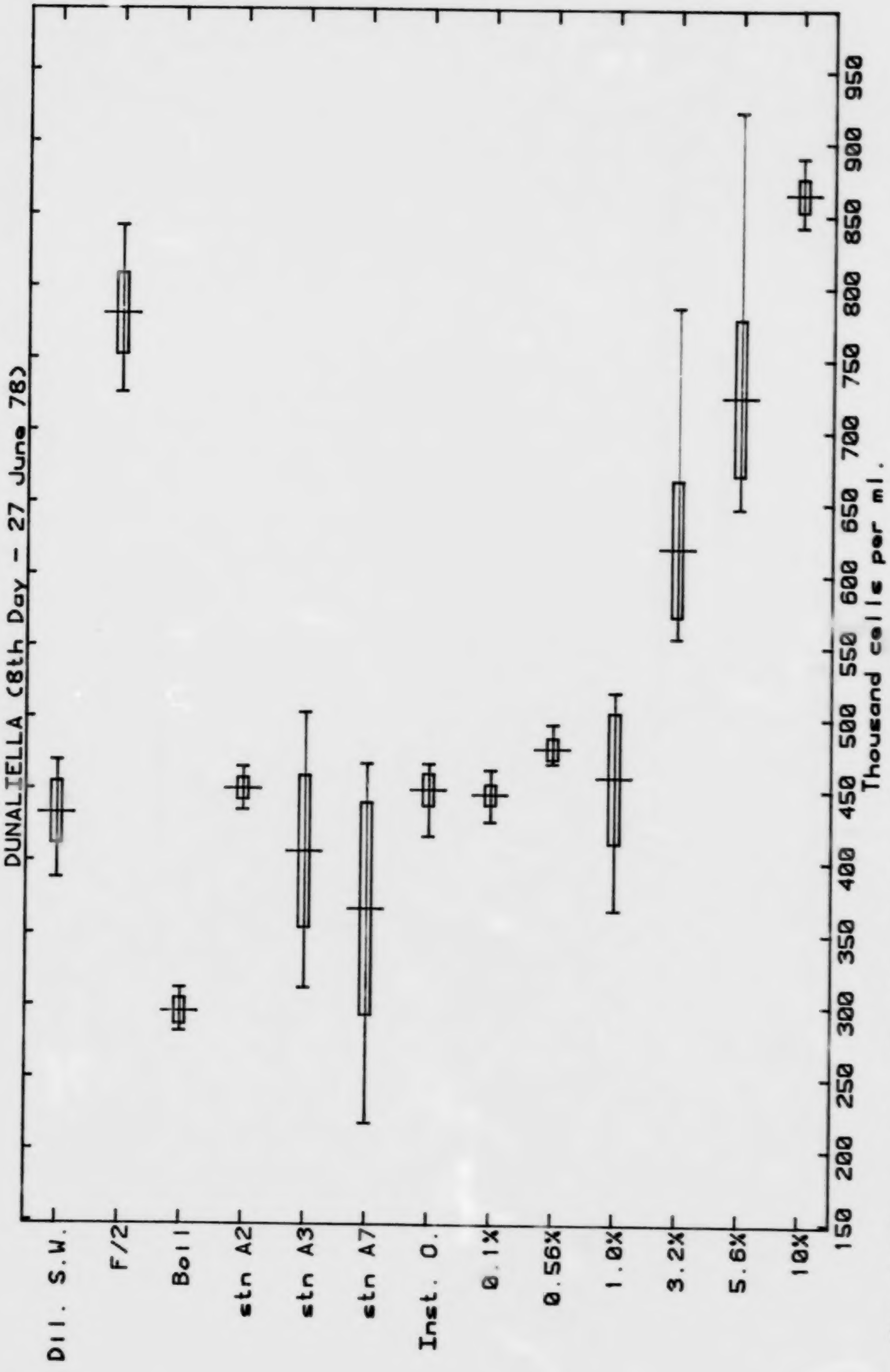
* The difference is significant (by anova, $P< 0.001$); Range & mean ± 2 S.E. are shown.

Figure 6



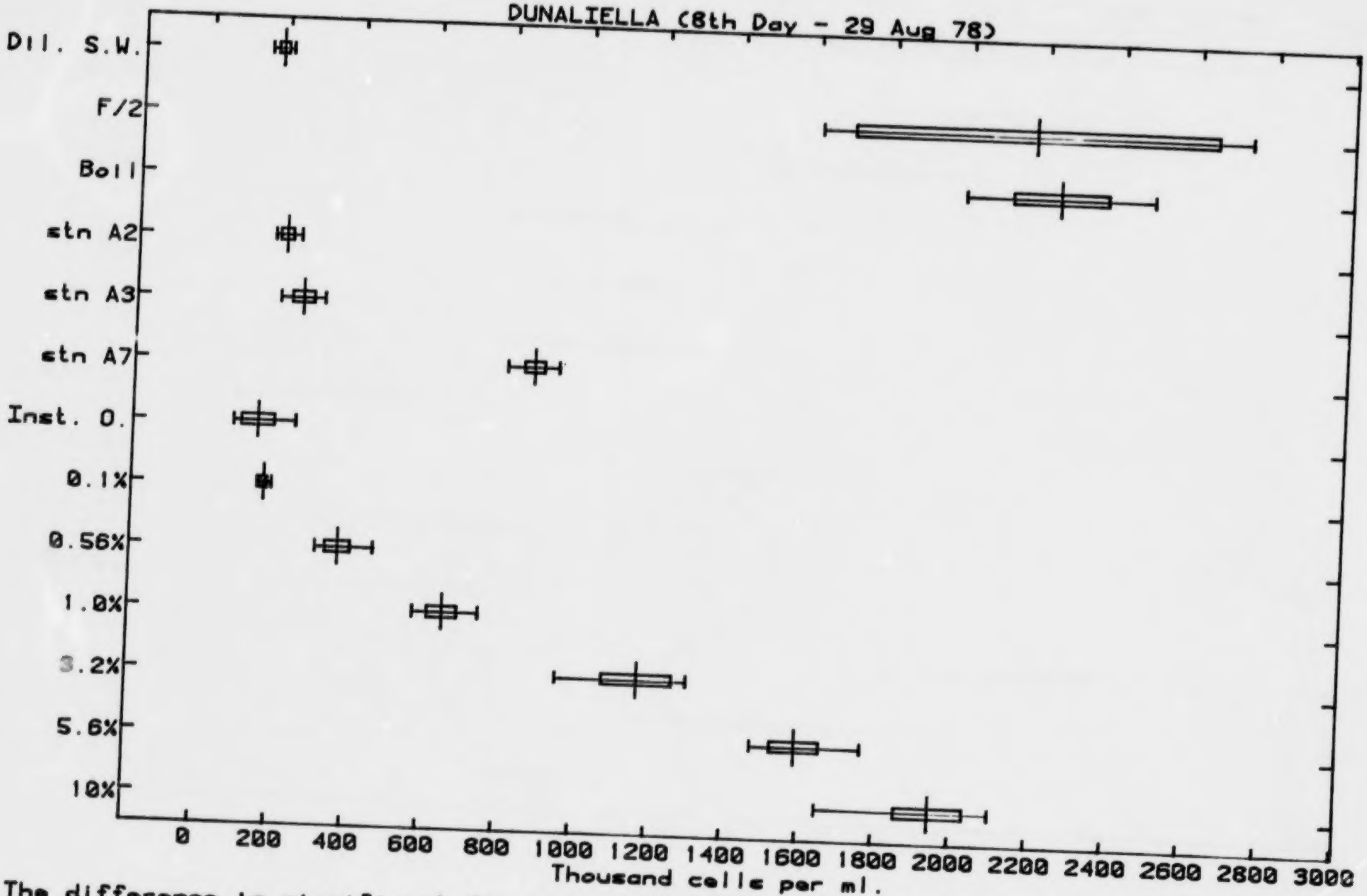
* The difference is significant (by anova, $P < 0.001$); Range & mean ± 2 S.E. are shown.

Figure 7



* The difference is significant (by anova, $P < 0.001$); Range & mean ± 2 S.E. are shown.

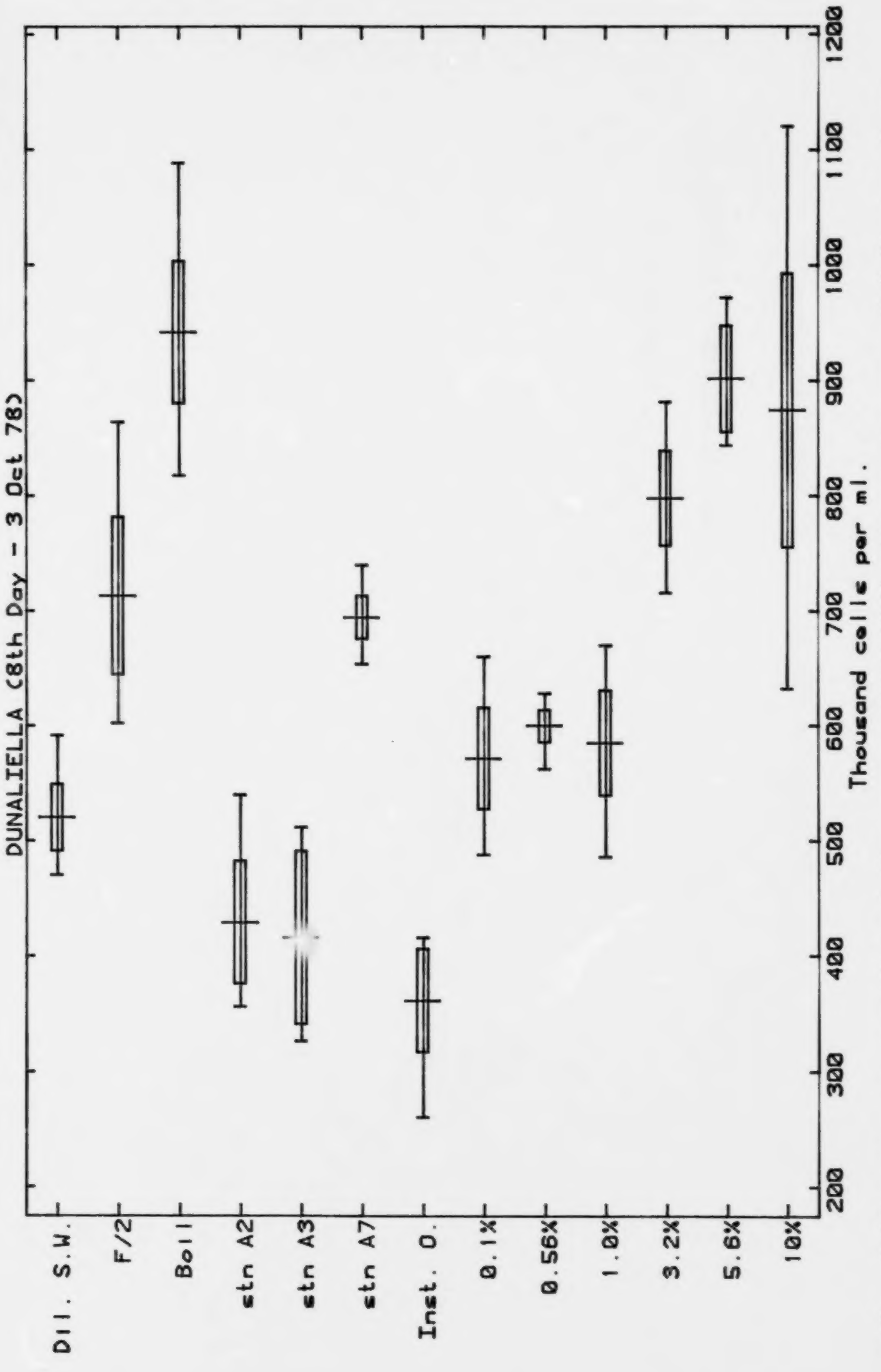
Figure 8



DUNALIELLA (8th Day - 29 Aug 78)

* The difference is significant (by anova, $P < 0.001$); Range & mean ± 2 S.E. are shown.

Figure 9



* The difference is significant (by anova, $P < 0.001$); Range & mean ± 2 S.E. are shown.

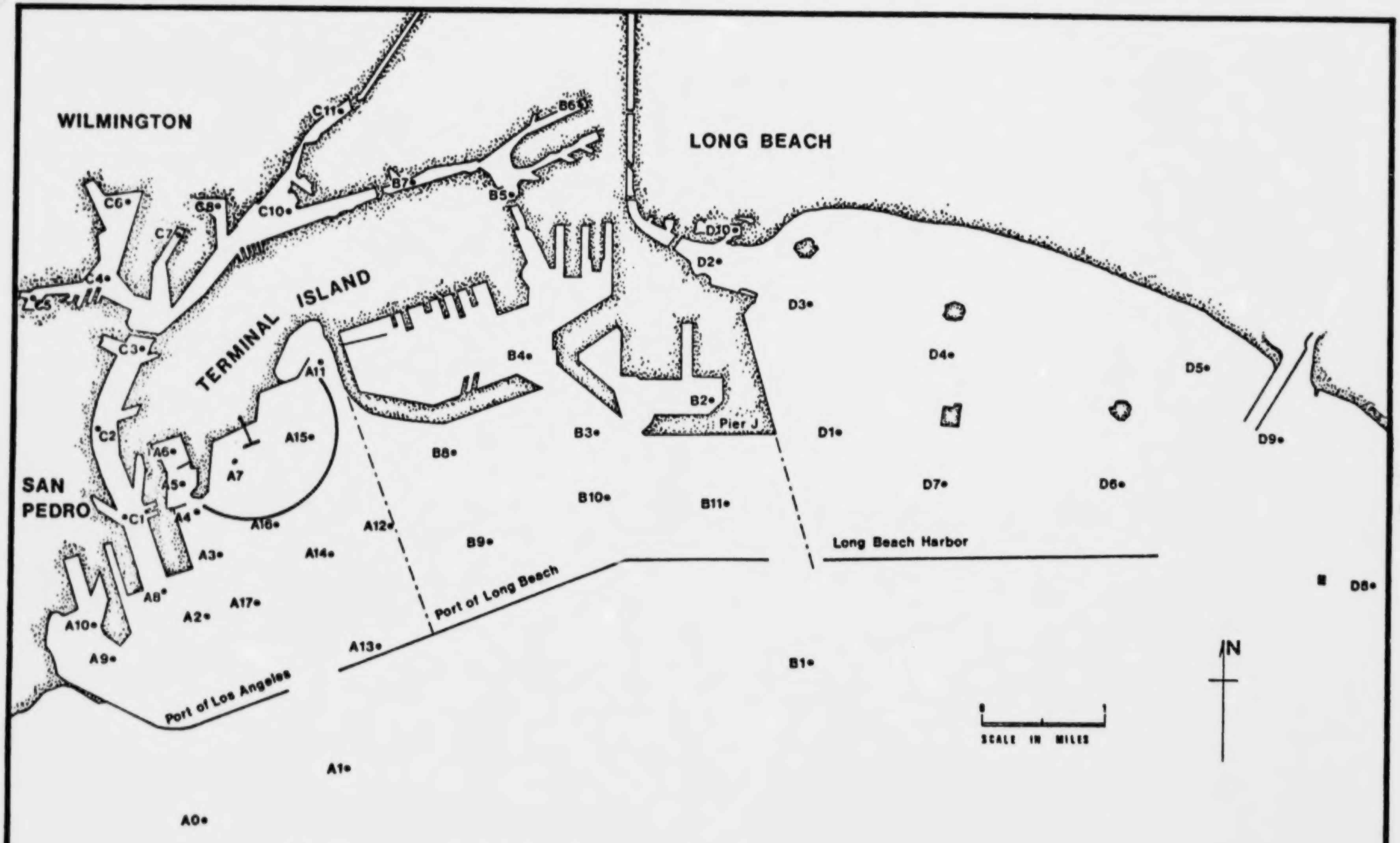


Figure 10. Estimated Zone of Phytoplankton Enhancement, 1978.

Harbors Environmental Projects

University of Southern California

Table 1. 8-Day Mean Specific Growth Rates (day^{-1})

Treatment	February	April	June	August	October
10%	.49	.32	.32	.39	.28
5.6%	.49	.29	.30	.36	.29
3.2%	.49	.27	.28	.32	.27
1.0%	.45	.21	.24	.25	.23
0.56%	.44	.19	.25	.18	.24
0.1%	.44	.18	.24	.08	.23
Stn Boil	.42	.33	.19	.40	.29
Stn A7	.46	.20	.22	.29	.25
Stn A3	.43	.20	.23	.13	.19
Stn A2	.43	.17	.24	.11	.19
Dilution Water	.44	.18	.24	.09	.22
Instant Ocean	.41	.19	.24	.07	.17
Enriched Medium (F/2)	.42	.32	.31	.40	.26

Table 2. Nutrient Levels at Harbor Stations

NO_2					
Stations	Feb	April	July	Aug	Oct
TITP Effluent	40	33	33	9	17
A7	.366	.166	.148	.440	.071
A4	.238	.102	.188	.114	.102
A11	.263	.091	ND	.061	.127
A3	.271	.159	.210	.103	.065
A2	.174	.079	.120	.053	.077
A12	.143	.136	.082	.088	.056
NO_3					
TITP Effluent	921 921	643 643	500 500	93 93	1329 1329
A7	3.697	3.222	15.172	5.156	8.924
A4	1.980	.709	0	.244	3068
A11	2.591	.747	ND	.385	1.858
A3	1.579	1.165	.191	.920	1.047
A2	2.379	1.023	.128	.478	1.466
A12	1.329	0	5.039	4.781	.372
NH_3					
TITP Effluent	700[1] (564)[2]	995 (1343)	1291 (1093)	2500 (1100)	0 (0)
A7	35.388	10.253	8.005	119.279	1.654
A4	5.314	2.669	2509	1.976	.331
A11	2.597	.971	ND	3.176	1.654
A3	8.032	4.186	1.912	4.941	.331
A2	5.979	1.941	1.553	3.176	1.433
A12	1.329	.789	1.195	1.623	3.198
PO_4					
TITP Effluent	--	--	--	--	--
A7	9.523	3.456	.456	12.391	3.024
A4	1.249	1.216	.728	.971	1.105
A11	1.594	.689	ND	1.689	1.295
A3	2.274	1.742	.631	1.362	.773
A2	1.792	1.304	.641	1.188	.706
A12	.761	.600	.697	.539	.453

[1] Monthly mean [2] Week of bioassay

TERMINAL ISLAND TREATMENT PLANT SECONDARY WASTE BIOASSAYS

INTRODUCTION

The purpose of a bioassay test series is to determine the effects of a particular substance on a group of selected organisms. Short-term (96-hour) tests can reveal only acute toxicity, whereas longer term tests (21 days or longer) are needed to identify sublethal, or chronic effects. Substances which may be contained within wastewater effluents discharged into the marine environment are of particular concern. In theory, if an effluent possesses a significant toxicity a concentration of this effluent can be found which causes a significantly higher mortality to occur in the marine organisms than does sea water not containing this effluent.

In the present study, the Terminal Island Treatment Plant (TITP) effluent was investigated. The effluent consists of 10-18 million gallons of secondary-treated sewage waste water released daily into outer Los Angeles Harbor. The original experimental design employed the use of four species of marine organisms which are common to the local nearshore waters of southern California. These were used in five sets of bioassays over different seasonal time periods. In addition, one other local marine organism was included in four of the bioassays and an additional set of supplemental bioassays was performed.

EXPERIMENTAL DESIGN

To assess the toxicity of TITP waste water, 96-hour bioassays were performed with twelve different test solutions. These solutions included six concentrations of sewage effluent, four field samples of receiving water and two types of controls. The concentrations of effluent used were 100, 75, 56, 32, 18 and 10 percent. The receiving water stations were located at progressively greater distances from the TITP outfall. These can be seen on the map, Figure 1, and were: 1) the TITP outfall; 2) at station A7, 550 m from the outfall; 3) at the Fish Harbor entrance buoy designated A3, 1525m distant from the outfall; and 4) the channel marker buoy A2, 1975m from the TITP outfall. One control was a solution of "Instant Ocean", and the other was filtered and ultraviolet-sterilized harbor water (designated henceforth as "house" water) from the USC Marine Facility at Berth 186, Los Angeles Harbor.

The four species originally selected as test organisms were *Neanthes arenaceodentata* (Polychaete worm), *Acartia tonsa* (planktonic copepod), *Fundulus parvipinnis* (California killifish) and embryos of *Engraulis mordax* (anchovy). The additional species employed in four of the five regular bioassays was *Emerita analoga* (the sand crab).

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The setup dates of the five regular 96-hour bioassays were February 13, April 17, June 23, August 21 and September 25, 1978. The supplemental bioassays were performed on January 29, 1979.

MATERIALS AND METHODS

Test Organisms

Test organisms were collected in various ways from several different sources. The *Fundulus* were taken by fish trap from a series of seawater canals in Venice, California. These fish were acclimatized in flow-through holding tanks of "house" sea water until the time of the bioassay setup. *Emerita* were sieved from the sand in the surf zone at Seal Beach. These were held in flow-through aquaria with bottoms covered approximately two inches by clean sand. The polychaetes (*Neanthes*) were readily available from laboratory cultures. On the morning of bioassay test starts, *Acartia* and *Engraulis* embryos were collected from plankton tows in Cerritos Channel and outside the Los Angeles breakwater respectively. Once in the laboratory, containers with these organisms were placed in water baths for acclimatization with "house" sea water.

Experimental Setup

A regular bioassay setup included two 10gal. aquariums for each of the twelve test solutions. This procedure was followed in order to separate the *Neanthes* from the *Fundulus*, which will predate upon them. These 24 aquaria were distributed amongst five waterbaths which maintained the temperature of all bioassay test solutions and controls at 17° C.

On the morning of the bioassay, secondary-treated effluent was obtained from the sampling site at the Terminal Island Treatment Plant. A 110 gal polyethylene tank was used to transport the waste to the bioassay laboratory. Before transferring the waste water to the bioassay aquaria, the salinity was adjusted with "Instant Ocean" to match the salinity of "house" sea water.

In order to dilute the secondary waste to proper test concentrations, the salinity-adjusted waste water was poured into appropriate test aquaria to a level predetermined for each test concentration. Various quantities of "house" sea water were then added to finish the filling procedure. In the case of aquaria containing 100% test solutions, no addition of "house" sea water was required. Similarly, no dilutions were necessary in the aquaria containing control solutions or receiving water samples; these were simply filled with the appropriate sea water.

When all test containers had been properly filled, the test organisms were distributed among them. Polychaetes were removed from the laboratory culture aquaria and placed in porcelain pans of "house" sea water. Since *Neanthes* can be cannibalistic, it was necessary to keep the test individuals separated within test aquaria. This was accomplished by using isolation tubes composed of 1 inch by 2 inch cylindrical snap-cup vials (polyethylene) whose lids and bottoms had been replaced with Nitex screen to provide a freely exchanging test chamber. One polychaete was loaded into each tube which was then placed into a bioassay aquarium. Each of the aquaria from one of the duplicate sets of twelve solutions received 20 housed individuals.

The *Fundulus* were placed into the other set of aquaria. These were netted from their holding tank and ten individuals were loaded into each of the appropriate twelve bioassay aquaria. The fish were inspected prior to loading, and any with pathological symptoms were discarded.

The *Acartia* and *Engraulis* were placed in separate plastic beakers suspended in the set of bioassay aquaria containing *Neanthes*. These beakers had screen windows in the sides to allow free circulation of water throughout the beaker while still retaining test animals. This method was intended to simulate better normal field conditions than does placing the organisms in crystalizing dishes in a separate water bath, as is usually done. The beakers allow the organisms to be in contact with the test solution in the 10 gal. aquaria, which are monitored daily for temperature, salinity, dissolved oxygen and pH. Monitoring those parameters in crystalizing dishes was impossible with available equipment.

A dissecting microscope was necessary for counting the proper numbers of *Acartia* and *Engraulis* embryos. Eyedroppers were used to remove samples of *Acartia* from their holding container. The contents of the dropper were emptied onto a depression slide and the copepods inspected and separated under the dissecting scope. Healthy individuals (intact and actively swimming) were removed with the eyedropper and transferred to the test containers. Twenty individuals were placed into each of the containers in the twelve test solutions.

Anchovy embryos were separated in a similar manner. One-day-old embryos which appeared healthy were selected and transferred to the appropriate screened beakers. Thirty individuals of *Engraulis* were used per test container.

When *Emerita* were used, they were screened from the sand on the bottom of the holding aquaria and counted out into the set of bioassay aquaria containing the *Neanthes*, *Acartia* and *Engraulis*. Twenty of these sand crabs were put into each test solution.

The screened beaker method of containing *Acartia* and *Engraulis* within the large bioassay aquaria often resulted in high mortalities. For this reason supplemental bioassays were performed. Samples of the twelve test solutions were placed in crystalizing dishes supported on racks in a water bath, into which test organisms were added. This method resulted in much lower mortalities among test organisms, but is less scientifically pleasing, as monitoring of test conditions in crystalizing dishes is impossible.

During the tests all aquaria were aerated to maintain the dissolved oxygen level. This was necessary for the larger test organisms; *Neanthes*, *Fundulus* and *Emerita*. The lighting cycle was 14 hrs. light/10 hrs. dark. None of the test organisms were fed during the bioassay. The temperature, salinity, dissolved oxygen and pH in each tank were monitored and recorded daily.

After 96 hours, a final reading of the above parameters was made and the test concluded. The surviving *Fundulus*, *Emerita* and *Neanthes* were counted by direct inspection while the organisms were still in the test aquaria. A dissecting microscope was used to count *Acartia* and *Engraulis* embryos and only live organisms were tabulated. Normally, these test results for all solutions and test species were tabulated within four hours.

All aquaria, plastic containers and glassware used in these bioassays were pre-washed with tissue-grade detergent and 10 percent hydrochloric acid. This procedure was followed to prevent contamination from previous bioassays.

RESULTS

The bioassay test results are presented in the six tables, 1 through 6. In these, the percent survival of test species is presented for all twelve test solutions and six 96-hour test periods. Occasionally, mortalities were known to be due to escaped animals and when possible these are noted.

Also included are the means of the daily recordings of measured experimental conditions; temperature, salinity, dissolved oxygen and pH. These are presented below the percent survival data with their standard deviations. The standard deviations are very small in all cases and it is judged by the experimentors that these parameters had negligible effects on the survival of test organisms.

DISCUSSION AND CONCLUSIONS

Two of the species employed in this series of bioassays, *Fundulus* (the California killifish) and *Neanthes* (a polychaete worm) showed no apparent difference in percent survival during any bioassay over the total range of test solutions. Survivorship was always near 100% for both of these species in all secondary waste dilutions, all receiving water samples and in both types of controls. A third species, *Emerita*, showed this same trend in three of the four bioassays in which it was used. The results indicate that the TITP effluent has no inherent toxicity for these organisms, even in the extreme case of the 100% concentration of secondary waste.

The *Acartia* results also support this conclusion and do not seem to show any differential survival in the various test solutions for different test dates. However, extremely low survivorship of these organisms in all solutions makes it difficult to draw conclusions from the data.

Engraulis data from the supplemental bioassays performed on January 29, 1979 mirror the *Fundulus* and *Neanthes* results. Here there were no significant mortalities in any test solution or for any of the four replicates per solution. However, the anchovy embryos did not maintain this trend on other bioassay test dates. The high survival during the January test may have been due only to the use of different techniques. The *Engraulis* were placed in crystalizing dishes in a water bath rather than in screened beakers suspended in test aquaria.

The remaining combinations display a different trend. This is towards a perceptibly higher mortality in high concentrations of effluent than in the control groups. This occurred with *Emerita* on April 17 and with *Engraulis* on February 13, April 17 and June 23, 1978. In these *Engraulis* bioassays, the screened beaker method, as described in Materials and Methods, was employed. As was mentioned there, this method was used to allow monitoring of experimental conditions within the *Engraulis* test containers. This method resulted in high overall mortalities in all solutions. This high mortality implies that these organisms were stressed to a greater extent than they would ever be in nature and would be more susceptible to toxic effects than in a natural situation.

Thus, conclusions of toxicity of the TITP effluent would be exaggerated. A similar situation may have occurred with *Emerita* in the April 17 test, as this species shows no significant mortality in any solution in any other test.

These inconsistent results between different test periods may also reflect variations in the character of the TITP wastewater effluent over time. In this case, receiving waters may be toxic to more delicate organisms, such as *Engraulis* embryos, during certain periods when the effluent discharged contains some particular toxic substance. This could occur while the same effluent waters remain innocuous to more hearty species such as *Neanthes* and *Fundulus*.

Wild harbor *Acartia* populations have not proven successful in bioassay tests for approximately the last two years. Conditions in the preferred inner harbor habitat may have changed to stress the populations so that they are less able to tolerate the capture and testing than previously. Numbers have been greatly reduced at times recently.

In general, one could conclude that if toxic effects should occur from the discharge of TITP effluent, they would be related to wastes introduced that were not there during the present tests.

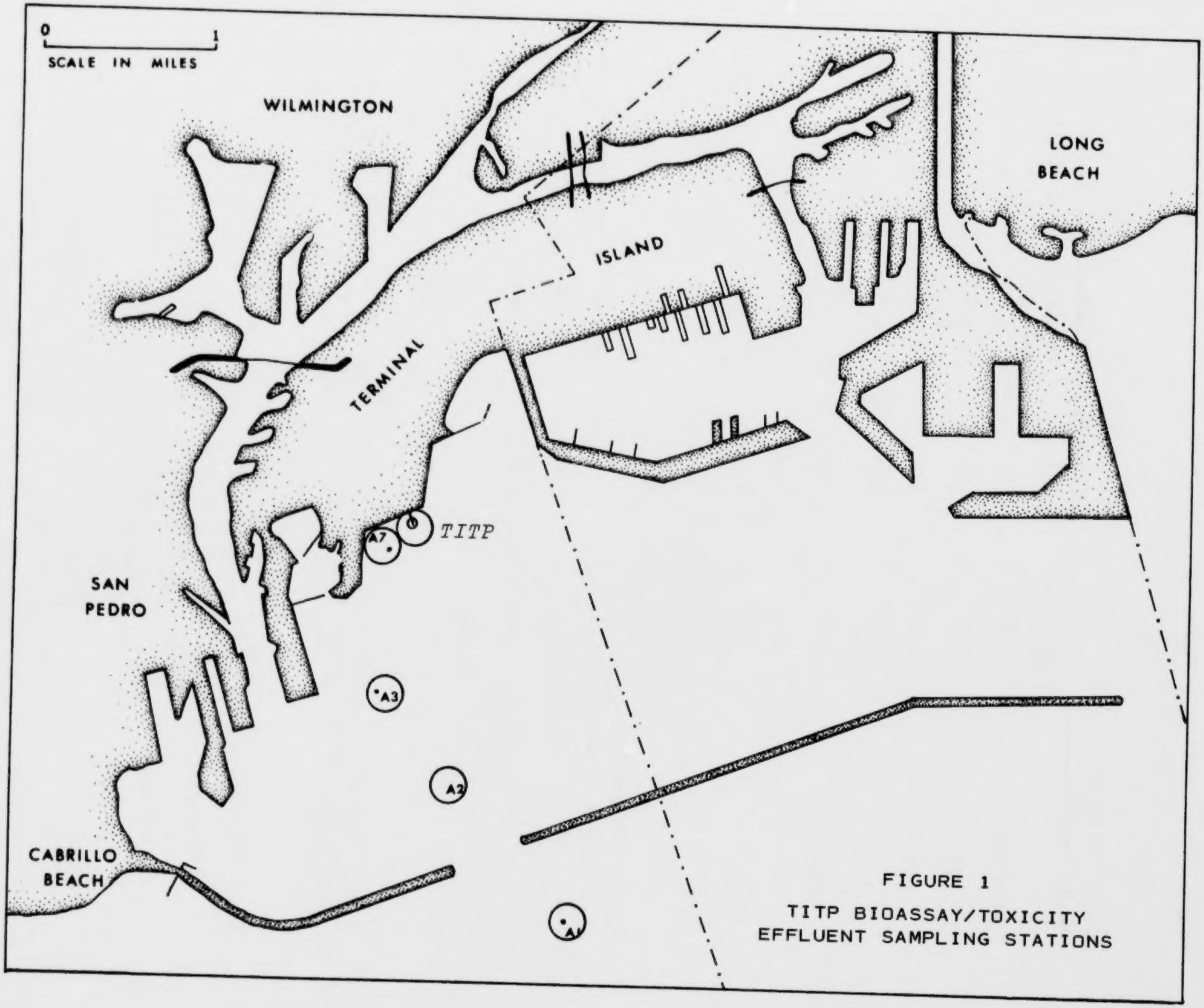

FIGURE 1
TITP BIOASSAY/TOXICITY
EFFLUENT SAMPLING STATIONS

TABLE 1. TEST 1 - FEBRUARY 13, 1978

CONCENTRATION OF EFFLUENT	PERCENT SURVIVAL			
	FUNDULUS	NEANTHES	ENGRAULIS	ACARTIA
CONTROL	100	100	90	0
10%	100	90*	67	0
18%	100	100	97	0
32%	100	100	100	0
56%	100	100	50	0
75%	100	100	53	0
100	100	100	13	0
RECEIVING WATER STATION				
BOIL	100	95*	0	0
A7	100	100	60	0
A3	100	100	80	0
A2	100	90*	87	0

*THESE APPARENT MORTALITIES ARE DUE TO ANIMALS MISSING FROM THE TEST CONTAINERS. THEY MAY HAVE BEEN EATEN, OR NOT SEEN UPON COUNTING.

EXPERIMENTAL CONDITIONS

TEMPERATURE - 15.6 ± 0.37 °C
SALINITY - 33.1 ± 0.26 PPT.
DISSOLVED OXYGEN - 8.1 ± 0.2 mg/l
PH - 8.0 ± 0.2

TABLE 2. TEST 2 - APRIL 17, 1978

CONCENTRATION OF EFFLUENT	PERCENT SURVIVAL				
	FUNDULUS	NEANTHES	ENGRAULIS	ACARTIA	EMERITA
INSTANT OCEAN CONTROL	100	90	50	0	100
LAB WATER CONTROL	100	100	23	3	100
10%	100	100	53	7	100
18%	100	100	33	0	95
32%	100	100	50	0	95
56%	100	100	3	3	90
75%	100	100	10	0	75
100%	100	95*	3	0	0
RECEIVING WATER STATIONS					
BOIL	100	100	0	3	95*
A7	100	100	0	0	100
A3	100	100	0	0	100
A2	100	100	10	3	90*

* THESE APPARENT MORTALITIES ARE DUE TO ANIMALS MISSING FROM THE TEST CONTAINERS. THEY MAY HAVE BEEN EATEN, OR NOT SEEN UPON COUNTING.

EXPERIMENTAL CONDITIONS

TEMPERATURE - 17.1 ± 0.3 °C

SALINITY - 33.6 ± 0.5 PPT

DISSOLVED OXYGEN - 7.3 ± 0.6 mg/l

PH - 7.8 ± 0.01

TABLE 3. TEST 3 - JUNE 23, 1978

CONCENTRATION OF EFFLUENT	PERCENT SURVIVAL				
	FUNDULUS	NEANTHES	ENGRAULIS	ACARTIA	EMERITA
INSTANT OCEAN CONTROL	100	75	40	0	100
LAB WATER CONTROL	100	100	25	10	100
10%	100	95*	15	25	100
18%	100	100	25	20	100
32%	90	100	20	15	100
56%	80	95*	10	0	100
75%	100	95	0	0	100
100%	90	95	0	0	100
RECEIVING WATER STATIONS					
BOIL	100	95*	15	50	100
A7	100	100	0	20	100
A3	90	100	5	65	100
A2	100	100	0	10	100

*THESE APPARENT MORTALITIES ARE DUE TO ANIMALS MISSING FROM THE TEST CONTAINERS. THEY MAY HAVE BEEN EATEN, OR NOT SEEN UPON COUNTING.

EXPERIMENTAL CONDITIONS

TEMPERATURE - 19.5 ± 1.2 °C
SALINITY - 32.8 ± 0.7 PPT
DISSOLVED OXYGEN - 7.7 ± 0.5 mg/l
PH - 7.5 ± 0.2

TABLE 4. TEST 4 - AUGUST 21, 1978

CONCENTRATION OF EFFLUENT	PERCENT SURVIVAL				
	FUNDULUS	NEANTHES	ENGRAULIS	ACARTIA	EMERITA
INSTANT OCEAN OCEAN	100	100	43	20	100
LAB WATER CONTROL	100	100	0	10	100
10%	100	95	17	27	95
18%	100	100	7	0	100
32%	100	100	10	0	100
56%	100	100	0	0	95
75%	100	100	0	7	95
100%	90	100	0	0	100
RECEIVING WATER STATIONS					
BOIL	100	100	10	13	100
A7	90	100	27	0	100
A3	100	95	10	0	100
A2	90	100	0	7	100

*THESE APPARENT MORTALITIES ARE DUE TO ANIMALS MISSING FROM THE TEST CONTAINERS. THEY MAY HAVE BEEN EATEN, OR NOT SEEN UPON COUNTING.

EXPERIMENTAL CONDITIONS

TEMPERATURE - 17.9 ± 0.3 °C
SALINITY - 32.0 ± 0.6 PPT
DISSOLVED OXYGEN - 9.6 ± 0.7 mg/l
PH - 8.2 ± 0.1

TABLE 5. TEST 5 - SEPTEMBER 25, 1978

CONCENTRATION OF EFFLUENT	PERCENT SURVIVAL		
	FUNDULUS	NEANTHES	EMERITA
INSTANT OCEAN CONTROL	100	90	100
LAB WATER CONTROL	100	95	100
10%	100	90	95
18%	100	100	95
32%	100	90	100
56%	100	100	95
75%	100	100	100
100%	100	100	95
RECEIVING WATER STATIONS			
BOIL	100	85	100
A7	100	90	100
A3	100	100	85
A2	100	100	100

EXPERIMENTAL CONDITIONS

TERMPERATURE - 20.8 ± 1.0 °C
SALINITY - 31.0 ± 0.4 PPT.
DISSOLVED OXYGEN - 9.3 ± 0.4 mg/l
PH - 8.1 ± 0.1

TABLE 6. SUPPLEMENTAL TEST - JANUARY 29, 1979

CONCENTRATION OF EFFLUENT	PERCENT SURVIVAL					
	NEANTHES	ENGRAULIS-1	ENGRAULIS-2	ENGRAULIS-3	ENGRAULIS-3	ACARTIA
INSTANT OCEAN CONTROL	93	83				13
LAB WATER CONTROL	93	100	100	100	95	6
10%	93	90	95	100	85	50
18%	93	97	90	95	95	60
32%	93	93	100	90	95	30
56%	97	97	100	100	95	60
75%	93	93	100	90	100	33
100%	90	100	100	95	100	67
RECEIVING WATER STATIONS						
BOIL	93	90	90	85	85	77
A7	97	97	100	90	95	60
A3	100	100	100	100	95	80
A2	100	90	85	90	85	87

EXPERIMENTAL CONDITIONS

TEMPERATURE - 12.3 ± 0.1 °C
SALINITY - 30.7 ± 0.9 PPT
DISSOLVED OXYGEN - 8.5 ± 0.6 mg/1
PH - 8.2 ± 0.1

VB 13

CANNERY WASTE AS A FOOD FOR ANCHOVIES

INTRODUCTION

In September of 1978 a report was prepared on the results of experimental feeding of anchovies on wet sludge obtained from the StarKist dissolved air flotation (DAF) treatment of fish cannery waste (Ralston, private report, 1978). In that experiment, one group of fish received supplemental feeding with sludge while the control group did not. The only food common to both sets of fish was the ambient plankton, contained in the water from Berth 186 in inner Los Angeles Harbor, that was being pumped continuously into their tanks. Under that regime, statistically significant differences were found in mortality rates. The fish that received supplemental feeding showed greater survival. However, growth curves showed that both groups lost weight, indicating that the amount of sludge selected for feeding was not sufficient to maintain the population. Feeding levels were on the conservative side because excess food in the tanks would cause bacterial problems for the anchovies. Although the weight loss was less in the fish receiving the sludge as a supplement, the results were not statistically significant. Mortality is always high in captive anchovies, and it is important to note that mortalities were significantly fewer in the sludge-fed group.

The present experiment was modified to present a higher level of overall feeding and was designed for better statistical analysis.

METHODS

Eight tanks containing 60 anchovies each was fed a maintenance diet of 15 grams of trout chow per day. Six of the tanks in replicate pairs were given 5, 10 and 15 grams per day of dried, ground sludge as a supplemental ration, respectively. The remaining pair of tanks received no supplement and served as the controls. All tanks were served with continuously pumped harbor water, as was the case in the earlier experiments.

Prior to the start of the present experiment, each fish was weighed and the average weight of the fish in each tank was calculated. At the end of 15 days the individual fish were again weighed and the average weight was determined for the surviving fish in each tank. The average fish weight per tank was used rather than average weight per fish to correct for the normal mortality of captive anchovies during the course of the experiment.

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RESULTS

Mortality, although high, averaged 41% and was not significantly different from tank to tank. The average weights in each tank at the start of the experiment, the average weights at the end, and the differences are shown in Table 1.

A linear regression analysis was performed on these net growths. The results are shown in Table 2 and plotted in Figure 1. The increase in net growth fits a rising straight line (F_s for a straight line of slope not equal to zero yields $P<.05$). Deviations from the straight line model are insignificant (F_s yields $P>.8$).

The fish receiving the maximum amount of sludge got twice the weight of food (15 gms sludge + 15 gms trout chow) as the control fish (15 gms trout chow only); yet their growth was triple that of the control (about .27 gms increase compared with about .08 gms increase in the controls). In this experiment, as in the previous one, the saturation point or maximum amount of sludge that can be utilized for growth was not reached.

DISCUSSION AND CONCLUSION

It is valid to conclude that the anchovies can utilize the sludge for growth. However, another set of experiments would be needed to examine the upper limits of the growth curves. The two sets of experiments have indicated that the wet or dry sludge is supportive of growth for anchovies. However, the California Department of Fish and Game and the Environmental Protection Agency have not permitted disposal of the sludge from the Terminal Island canneries at sea. Instead, this nutrient source is being dumped in a landfill. When the sludge is wet, it creates odors as microbial biodegradation occurs. Drying the sludge is energy demanding and adds to waste disposal costs, which now include sewerage of the liquid wastes.

Questions raised previously on metals content of sludge are being addressed by the canning industry. The Environmental Protection Agency reiterates that containment of sludge on land, with attendant odor and leaching probabilities, is better for the environment than dispersion into open waters of the ocean. This appears to constitute a wasteful solution for a nutrient source, which has potential for a mariculture nutrient or for feeding natural marine populations. Feeding sludge to pigs is also being tested elsewhere.

LITERATURE CITED See Section VI

Table 1. Average weights and net change in weight of fish fed on different supplemental rations of sludge

gms sludge	replicate	average fish weight start	end	weight increase
0.0	1	2.04	2.21	0.18
0.0	2	2.53	2.51	-0.02
5.0	1	2.16	2.25	0.09
5.0	2	2.10	2.25	0.15
10.0	1	2.29	2.47	0.18
10.0	2	2.02	2.21	0.18
15.0	1	2.08	2.39	0.32
15.0	2	2.27	2.50	0.23

Table 2.   LINEAR REGRESSION ANALYSIS

```
ANCHOVY FEEDING STUDY
--

X represents grams sludge in feed per day.
Y represents growth of average fish (grams).

For 8 points supplied, the mean of X is 7.5000,
                       and the mean of Y is 0.1627.

The variance of X is 35.7143 and of Y is 0.0097.
--

The regression equation is:  Y= 0.0129 X + 0.0660.

95.0% confidence limits for the slope are 0.0056 & 0.0203.
--

ANALYSIS OF VARIANCE:

SOURCE      SS          df         MS          Fs          P

groups      0.0431      3          0.0144      2.3467      0.214
 linear       0.0416      1          0.0416   57.0813      0.017
 dev.         0.0015      2          0.0007     0.1192      0.891

error       0.0245      4          0.0061

total       0.0676      7
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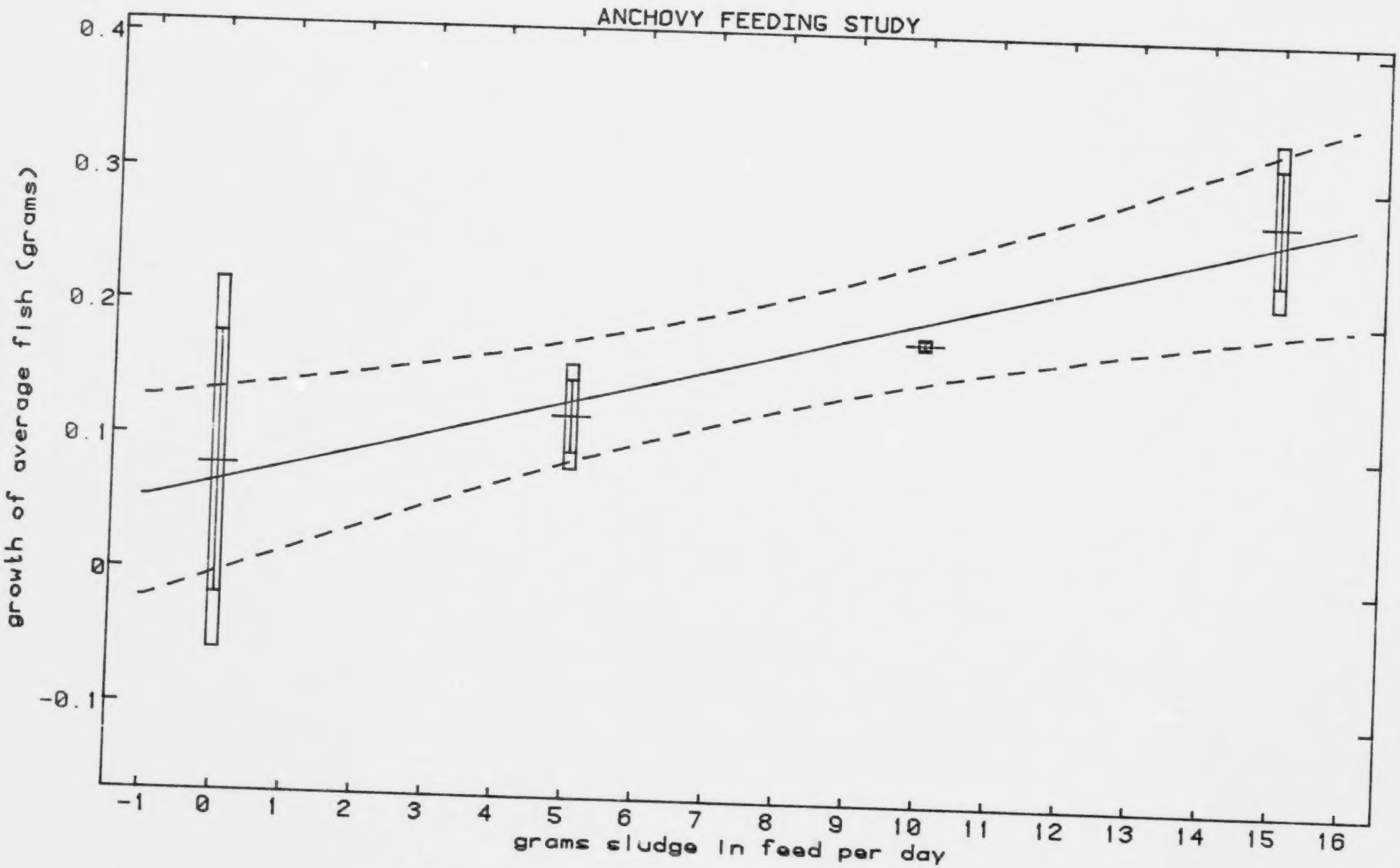


FIGURE 1. THE REGRESSION LINE AND 95% CONFIDENCE LIMITS ARE PLOTTED WITH THE RANGE AND 2 S.E.'S OF THE ORIGINAL DATA AT EACH X VALUE.

V D1

GROWTH AND STIMULATION OF INVERTEBRATES IN THE WASTE PLUME

BIOSTIMULATION OF *MYTILUS EDULIS*

INTRODUCTION

Biological laboratory studies cannot simultaneously reproduce the synergism of physical and chemical factors which occur in natural ecological systems. For this reason, it is desirable to augment laboratory studies with actual in situ biological experiments. In this study, in situ growth experiments help to assess the impact or biostimulatory effect of Terminal Island Treatment Plant (TITP) wastes on the marine environment.

The bay mussel, *Mytilus edulis*, is a common fast-growing, filter-feeding mollusc, which occurs in all semi-protected waters of southern California, as well as in many other areas of the world. Any hard substrate which is not subject to periodic artificial disturbances and which lies within the tidal levels of approximately +1 to -3 meters from mean lower low water, is usually encrusted with mussel growth. The metabolic potential of these dense mussel beds is significant to the ecological balance in coastal marine waters. For these reasons, *Mytilus edulis* was chosen as an indicator species for determining the growth potential of organisms affected by the TITP wastewater outfall.

EXPERIMENTAL DESIGN

TITP effluent has a substantially lower salinity than normal harbor waters. This results in a lower density and a tendency of the effluent to form a surface lens, which becomes less distinct and more mixed with increased distance away from the outfall. Complex harbor circulation patterns also affect the horizontal distribution and mixing of TITP waste waters. In order to take into account this three-dimensional effluent distribution, a vertically -- as well as horizontally -- stratified sampling scheme must be employed.

In this experiment, three depths were designated for suspending samples of mussels. These were one meter, two meters and three meters deep. These depths were represented at four stations at various distances from the TITP outfall during each of four one-month experimental periods. Station locations were: 1) at the TITP outfall, 2) at the buoy designated A7, 550 m distant from the outfall, 3) at the Fish Harbor entrance buoy designated A3,1525 m from the outfall, and 4) at the channel marker buoy A2, 1875 m distant from the outfall (see Figure 1). The experimental periods were: 1) May 18-June 18, 1978, 2) August 9-September 9, 1978, 3) October 24-November 24, 1978, and 4) December 5, 1978-January 5, 1979.

Each sample initially consisted of 40 mussels. This sample size was selected so as to allow for some natural mortality and still be large enough after one month for optimal statistical analysis. Any mortalities observed were determined to be mainly due to predation and unrelated to effluent concentrations. Each mussel in the samples was measured to an accuracy of .005 cm at the beginning and end of the test period, in order accurately to determine individual mussel growth.

MATERIALS AND METHODS

In nature, *Mytilus edulis* occurs in dense clumps in association with many other fouling organisms. In this complex association, *Mytilus edulis* compete with the other fouling organisms, as well as with each other, for filterable food particles in the surrounding water. These complex interactions in intact mussel clumps make it impossible to determine accurately growth potentials for individual mussels maintained in receiving waters.

To alleviate this problem, mussels were cleaned of all fouling organisms and suspended separately from each other. This was accomplished using specially designed and constructed mussel racks. The racks also permitted keeping track of individual mussels, so that monthly growth was determinable for each individual. The determinations greatly augmented statistical analysis of the data.

Mussel Racks

Figure 2 is a diagram representing one of the four mussel racks. Each rack consisted of three ¼ inch thick stainless steel hoops arranged in a vertical array at one meter, two meter, and three meter depths. Each hoop was connected to the next one by three 3/16 in diameter stainless steel cables. Stainless steel thimbles and "nico-press" fittings were used to attach cable ends to prevent chafing. Racks were held away from buoys by rigid stainless steel struts guyed to buoy chains by stainless cables. Stainless snap-shackles were used to attach the support struts to a bridle extending from the bottom hoop of the rack. These facilitated quick attachment and removal of mussel racks. Racks were supported vertically in the water column between the rigid support strut and a submerged high impact plastic float attached to the top hoop. This arrangement was designed to always keep the mussels at their respective test depths and to circumvent vandalism.

A folded-over 6 inch strip of ¼ inch stretched mesh, knotless nylon netting was sewn around the circumference of each hoop. Each folded strip contained 40 individual heat-sealed, numbered pockets to hold each of the 40 individual test mussels per hoop. Once a mussel was placed into a pocket, it remained there throughout the month-long experimental period. At the end of the period, each could be removed, remeasured, and the final length compared to its initial length to determine individual mussel growth. Since this arrangement maintained mussels separately from one another and away from other fouling organisms, competition with other filter-feeders was minimized. All of the 40 mussels at a particular depth and location should have had an equal opportunity to feed during any given experimental period.

Loading of Mussels

All mussels used in this experiment were collected from the same group of pilings marking the east side of the main channel entrance to inner Los Angeles Harbor. These pilings lie approximately 100 meters offshore in about 60 feet of water. This site receives more surge from passing ships than most harbor areas, resulting in mussel growth with minimal fouling by other organisms. These relatively "clean" mussels were ideal for this experiment as they required little initial cleaning prior to measurement and loading into mussel pockets. Mussels were always collected at low tide a few days prior to the start of an experimental period and held in running sea water in the laboratory until used.

Mussels were loaded into their respective pockets on the mussel racks one day before field deployment. The procedure incolved the random selection of an individual mussel from a holding tank; the careful removal of fouling organisms off the mussel; measurement of the maximum length of the shell's long axis to the nearest 1/20 mm (with an outside vernier calliper); the recording of this measurement; and finally, the section of the mussel into its respective nylon net pocket on the rack. When a mussel rack was fully loaded, it was stored in a 500 gallon holding tank with flowing sea water until deployment in the field the following day. After one month in the field, racks were returned to the lab, the mussels individually removed from their pockets and remeasured as before. Mussels were discarded after use and new ones obtained for each of the four one-month experimental periods. The purpose of this was to prevent any residual effects of one test from influencing the outcome of other tests.

RESULTS

Over 3,500 mussel measurements were taken from three depths, four locations and four one-month experimental time periods. This mass of data was computerized and analyzed statistically to determine whether any significant differences occurred between any of the experimental parameters.

Summary of Analysis

Figures 3 and 4 and Tables 1 and 2 are the results of two regression analyses performed to determine whether absolute length increase or per cent length increase should be used for the analysis. A subset of 96 individuals was drawn from the data for this analysis (two randomly selected from each of 48 samples). Within this subset, absolute length increase remained constant over the entire range of the starting sizes (that is, the slope of the regression line was not significantly different from zero), so may be assumed not to be a function of size. This was not true for per cent length increase, which fell off with size increase. As a result, absolute length increase was used for all remaining analyses.

This experiment fits a model I, factoral design ANOVA (three factors with replicates). The analysis was performed after the manner of Hartley (1962). This method requires a balanced model. Since there was missing data due to mortality, the smallest sample was used as the replicate size (17 individuals), and individuals were randomly eliminated from the other samples to bring them down to the balanced sample size.

In the Hartley method, the replicates are considered as a fourth factor. Following computation, all terms containing the "replicate factor" (factor A) are pooled to form the error term. The results of the Hartley method are shown in Table 3, and the pooled ANOVA in Table 4.

Only the variations due to season and location and their interaction were significantly greater than the overall growth variation. This conclusion is supported by Figures 5, 6 and 7, in which the means, ranges and two standard error boxes for each factor (all individuals pooled) are plotted. The standard errors overlapped among depths, whereas they did not among locations and seasons.

Figure 8 presents the interactions of season and location. The growth with season is plotted for each test location. It appears that the increased August to November, 1978 growth seen at A7 and A3 was enhanced by the TITP outfall. Racks at station A2, however, appeared to have reacted differently, for unknown reasons. The nutrient supply may have been lower at A2.

DISCUSSION AND CONCLUSIONS

Among the factors investigated that might be related to growth rate of *Mytilus edulis* in the harbor it was found that depth and size at the start of the experiment were not significant. Season and proximity to the outfall were statistically significant.

As shown in Figure 8, the seasonal growth rates for mussels held for one month at the TITP boil and at stations A7 and A3 followed similar trends. Low rates of growth were found in May-June, 1978 and December 1978-January 1979. Higher values were found for the two experimental periods between those dates. The station at the boil consistently showed the highest growth rates of the three and station A7 the lowest.

Station A2, the farthest from the outfall area, showed highest growth rates of all stations in the spring (May-June 1978) and winter (December 1978-January 1979). During the summer and fall periods, when the other stations showed enhanced growth rates, this station showed reduced growth rates, the lowest among the four stations.

The trends in the seasonal growth rates clearly fall into two categories. Stations at the TITP boil, A3 and A7, are those that are influenced by the wastes discharged from TITP into that area. Station A2 is the farthest from the discharge area and the closest to the open sea. Growth rates exhibited by mussels suspended there probably reflect more the influence of the ocean waters rather than the effluent from the treatment plant.

It is interesting to speculate on the relationship which the growth rate curves may have to the suspended solids and other material in the TITP effluent rather than to seasonal factors. Mussels are filter feeders, whose growth may depend on the concentration of food particles in the surrounding waters. It is known that particulate matter was copiously discharged during the summer of 1978, when the treatment plant was upset. The growth rates of the mussels rose at this time, when the growth rate at A2, reflecting oceanic influence, dropped. The higher fall growth rates may be a reflection of the same influences governing the higher values at A2. The similarity does not hold for the winter values.

At the TITP boil, higher oxygenation from the plant and from the turbulence may account for the much higher growth level in the summer than at station A7, the next closest location. Nutrient levels would not be greatly different between the two sites. At station A3, circulation is also probably better than at A7 because of its less sheltered location. The drop in growth at A2 is unexplained, except that A3 is generally higher in nutrients such as NO_2, NO_3 and NH_3. It is possible that some upwelling occurred during the winter period outside the harbor, that would have brought mutrients into the main channel on tidal exchange.

BIOSTIMULATION OF INVERTEBRATES

INTRODUCTION

The water column of marine areas with polluted or unconsolidated bottom sediments may be richer in fauna than is indicated by bottom (benthic) sampling, and zooplankton tows capture only small samples in time and space. There are many organisms that are temporarily represented in the plankton as eggs and larvae, which settle out when suitable substrates are available, but otherwise perish. The settling rack technique offers an artificial substrate, suspended from buoys and docks at 3m depth. Results of the 1973 and 1974 studies were discussed in AHF (1976).

In the usual harbor monitoring, racks are exposed for one month periods. Fauna so collected differ greatly in space and in time in the harbor. Therefore, in the present study, racks were all exposed for one month at a single location, and then transferred to separate sites for evaluation of further growth during the second month.

METHODS

Quantified samples of one month old settling communities were transplanted to four locations on a transect from the TITP boil to the A2 channel marker buoy in the outer Los Angeles Harbor. Analysis of these samples allows a good comparison of the *in situ* growth and recruitment characteristics of settling organisms throughout the TITP effluent plume.

The substrate for recruitment and growth of settling community samples was provided by settling racks developed by Dr. John Soule at USC (Soule and Soule, 1971). These racks consist of paired, open, wooden microscope slide boxes suspended vertically from a single wooden cross support by 5/16 inch nylon line. Twenty-five glass microscope slides are inserted into slide slots in each of these boxes, which are then covered with plastic screen, providing protected internal settling surfaces in addition to the external surfaces which are exposed to normal wave and current conditions.

The paired settling racks were first soaked in filtered and ultraviolet-sterilized sea water for two weeks in the laboratory. This procedure prepared the settling surfaces by leaching out any toxic or inhibitory chemicals from the wood and glue used in construction of slide boxes. In addition, this allowed an accurate determination of the wet weight of settling racks prior to the accumulation of any settling biomass. The racks were weighed on a grocery scale to the nearest ¼ ounce the day of initial deployment in the field.

On June 14, 1978 four pre-soaked and weighed settling racks were deployed at the A2 channel marker buoy at a depth of two meters. This station was selected as the control site from which the one-month-old settling community samples would be acquired. It is approximately 1875 meters away from the TITP boil towards the Angels Gate entrance to the Los Angeles Harbor. Selection of this station as a control site is justified by past hydrographic evidence (Robinson and Porath, 1974), suggesting a minimal effect at this location from the TITP effluent plume.

One month later, on July 14, 1978, the four settling racks were recovered from the A2 channel marker buoy, wet-weighed immediately on a grocery scale to the nearest ¼ ounce and photographed close up on both sides with a 35mm Canon AE-1 camera. The slides produced from these photographs were used to determine general species composition of the settling communities prior to deployment at test sites. Care was taken in handling of the settling racks so as to keep the fauna alive by minimizing air exposure of settling organisms and other related physiological stress.

Four test locations were selected for the deployment of the one-month-old settling community samples obtained on the settling racks. These were: The control station at the A2 channel marker buoy stations, A3, A7, and directly at the TITP effluent boil. The distances from these first three stations to the TITP boil are approximately 1875 meters, 1525 meters and 550 meters respectively. All racks were resuspended at the previous depth of 2 meters.

On August 14, 1978, one month after deployment at test locations, all settling racks were recovered. Weights and photographs were obtained in the same manner as on July 14, 1978, and all four settling racks were preserved in 10% formalin solution for subsequent laboratory analysis of species composition and numbers.

RESULTS

Biomass of Settling Organisms

Data obtained from live weight measurements of intact settling racks are presented in Table 1, in which the initial weights of settling racks before field deployment, as well as the weights after one and two months in the field, are given. The net biomass weight of organisms has been determined from the gross weights. This was accomplished by subtracting the initial wet weight of laboratory-seasoned settling racks from the weights after one and two months respectively. These biomass values are also presented in Table 1.

With these data, the percent increase in biomass of these sample settling communities can be determined. This is calculated by subtracting the first month biomass for a given location from the biomass found at the end of the second month, and then dividing this difference by the first month biomass again.

$$\text{\% increase in biomass} = \frac{\text{2nd month biomass} - \text{1st month biomass}}{\text{1st month biomass}}$$

The values for the percent increase in biomass are also given in Table 5 for each of the four settling rack locations. These values have been represented graphically in Figure 9 to show how the percent biomass increase of these settling organisms relates to distance away from the TITP wastewater outfall.

Species Composition

The number of species (or taxa) on the racks was increased by the two-month exposure and double racks, so that direct comparisons with one-month single racks would be misleading. In general, there were 13 more taxa at A3 in the experiment than from a comparable period one-month single rack exposure, and 24 more taxa at A2 than on a single one-month rack in August. The principal differences in space were that station A7 had the highest number of taxa but fewer phyla (or equivalent level). The differences are slight, however, between A7 racks and A2 in numbers, but A2 had more phyla.

Text Table 1. Comparison of Species/Taxa on Settling Racks

Number	Boil	A7	A2	A3
species/taxa	40	47	46	41
phyla	10	9	11	10

CONCLUSIONS

In the set of experiments, the percent biomass increase was greater at station A7, as compared with the TITP boil. Station A2 racks had the highest percent increase, while station A3 racks were the lowest. The increase at the lowest, however, was still nearly 100%. Since A2 racks remained at the same site for the entire period, they would possibly have had an advantage in not being transferred to a different regime.

Contrary to the concept that increase in biomass is traded for reduced numbers of species or taxa, A2 and A7 had the highest and second highest percent increase in biomass respectively, whereas they were almost identical in having the highest number of taxa. Station A2 had the most phyla of the four, but the differences are probably not significant.

It is clear that the TITP effluent plume is not inhibiting the growth of water column invertebrates, but is providing nutrients to a food chain which enhances growth.

FLOW-THROUGH BIOENHANCEMENT STUDIES OF THE TERMINAL ISLAND TREATMENT PLANT SECONDARY WASTE EFFLUENT

INTRODUCTION

The Terminal Island Treatment Plant (TITP) effluent is an important nutrient source, as is shown in the studies on *Mytilus edulis*, settling rack invertebrates, and Phytoplankton in receiving waters. The present study was designed to carry these investigations further and to assess the bioenhancement potential of the TITP effluent in a totally simulated laboratory ecosystem.

Two main questions are investigated here. The first is: Can growth occur in selected species from this simulated ecosystem during long-term enrichment of the TITP waste water? The second question is: Can the ecosystem purify these simulated receiving waters biologically to make them more esthetically pleasing in compliance with water quality criteria?

MATERIALS AND METHODS

a. Simulated Ecosystem Growth

In the first part of this experiment, the question of whether TITP effluent can support growth in a simulated ecosystem is investigated. For this, a highly nutrient-rich component of the TITP waste was used. This was pre-DAF-treated fish cannery waste water and represented a large volume component of(and a large percentage of the BOD contained in) the TITP waste influent.

Approximately 1,000 gallons of this pre-DAF cannery waste was trickle-fed into the experimental setup during the 1½ month test period from November 7, 1977 to December 22, 1977. The flow rate was maintained at approximately 100 ml/min.

The experimental setup consisted of four eight-foot-long fiberglass troughs arranged in pairs, so that the outflow of the first in a pair would flow into the second. One of these separate two-trough systems was designated as the test set to which the DAF cannery waste was fed and the other was a control which received only laboratory sea water.

Into each of these sets of troughs was loaded 100 weighed and measured clams *Mercenaria mercenaria*. Each week these clams were rearranged within their respective troughs to provide uniform feeding conditions for all clams.

Ten specimens of *Fundulus parvipinnis*, the California killifish, were also used per set of troughs. These were also weighed and measured prior to loading. In addition, a third *Fundulus* group was set up in the laboratory, which was fed their usual diet of trout chow.

Other organisms were included in these troughs, such as the algae *Enteromorpha* and the tectibranch mollusc *Aplesia californica*, but only the *Mercenaria* and *Fundulus* were quantified.

b. Biological Purification of TITP Effluent

In the second part of the study, a simulated mussel bed and phytoplankton ecosystem was tested to determine its ability to purify waste waters biologically. The TITP secondary waste effluent was used in this study. This effluent was first diluted to 32% with Harbor Laboratory sea water, inoculated with a sample of harbor phytoplankton and allowed to incubate in the sun until the plankton reached a thick "bloom" stage. The initial setup date was March 16, 1979 and the phytoplankton culture was trickle-fed to the test troughs on March 28, 1979. This allowed 12 days for the phytoplankton to utilize the nutrients within the TITP waste water solution.

Four sets of two 8-foot-long troughs each were used in this experiment and set up in a similar manner as in Part a. Into these, a layer of clumps of the mussel *Mytilus edulis* was then added, which contained the barnacle *Balanus* sp., the green alga *Enteromorpha* sp., the nudibranch *Hermisenda* sp., the anemone *Anthropleura* sp., as well as many unidentified polychaetes, flatworms, tunicates, hydroids and marine organisms commonly found in mussel associations. In addition, 50 clams (*Mercenaria mercenaria*) were added to each lower trough.

Flow rates were calculated for each of the four sets of troughs to give sewage effluent concentrations of 0 (control), 1.35, 5.6 and 10 percents. A total of 9.9 L/min of flow was maintained in each set of troughs. To maintain the above effluent concentrations, while using the stock TITP fffluent solution of 32 percent effluent/68 percent laboratory sea water, varying proportions of TITP effluent to laboratory sea water were used to make up the total 9.9 L/min flow. The control set had no sewage solution and 9.9 L/min laboratory sea water, concentration #1 had 0.4 L/min sewage solution and 9.5 L/min laboratory sea water, concentration #2 had 1.7 L/min sewage solution and 8.2 L/min lab sea water, and concentration #3 had 3 L/min of sewage solution and 6.9 L/min of lab sea water. These flow rates were monitored throughout the experiment with precision flow meters and adjusted when necessary with individual "ball" type PVC valves.

The total valume of the sewage solution in the phytoplankton culture aquaria was 2036 L. With the above-mentioned sewage flow rates, this allowed 6 hours of continuous flow.

To determine biological purification, 3 replicates of standard nutrient samples were taken for NH_3, NO_2, NO_3, and PO_4 for each sample. Samples of the effluent solution were taken on the day of initial setup (March 16, 1979), and just before and after the trickle feeding experiment. In addition, nutrient samples were taken from the outflow of each of the four sets of test troughs. These were taken just prior to the start of trickle feeding; after two hours of feeding; after four hours of feeding; when the feeding was stopped; and two hours after finishing the trickle-feeding process. All nutrient samples were processed and analyzed in the same manner as in section I of this volume.

RESULTS

In Part a of the flowthrough studies, *Mercenaria* and *Fundulus* growth in pre-DAF cannery waste was investigated. The *Mercenaria* data are represented by shell length and total weight differences which resulted from six weeks of being fed pre-DAF waste water. These data have been analyzed and are presented in the graphs, Figures 10 and 11. Data recorded from the *Fundulus* was also analyzed and are presented in the graph, Figure 12.

Results of Part b are evaluated on the basis of ammonia levels remaining in the effluent. The data are presented in Figure 6.

DISCUSSION AND CONCLUSIONS

a. Simulated Ecosystem Growth

In this test pre-DAF cannery waste was trickle-fed to a simulated ecosystem for a period of six weeks. The growth of the organisms within this ecosystem was evaluated by measuring and weighing two indicator species, *Fundulus parvipinnis* and *Mercenaria mercenaria*, before and after this flow-through test.

The results of the *Mercenaria* measurements (Figures 10, 11) indicate the extremely slow growth of this organism. No significant growth occurred in weight or shell length during the six week experiment. Mortalities were negligible in both control and test clams, however, indicating that neither treatment was detrimental to these organisms.

There were three test groups in the *Fundulus* experiment; unfed controls, the treatment group fed pre-DAF waste, and a second control fed the normal laboratory diet of trout chow. As can be seen from Figure 12, the unfed control shows a definite decrease in size over the experimental period. The pre-DAF treatment group, however, did not significantly shrink and the graph (Figure 12) indicates a slight increase in mean fish size. From this one can conclude that trickle feeding of pre-DAF waste is more beneficial to these organisms than not being fed at all.

The control group fed trout chow seems also to show a positive growth trend. Even though the growth in this group is not significantly different from the treatment group, the upward shift of the mean size of fish is greater than the corresponding shift for the pre-DAF-fed fish. This is not surprising, as these fish would be expected to show rapid growth on this high protein balanced diet which they were accustomed to eating.

In conclusion, the results of Part a suggest that the cannery waste now subjected to TITP secondary waste treatment could have a positive biostimulatory effect on some marine species. At present, this nutrient is eliminated from the receiving waters.

b. Biological Purification of TITP Effluent

The design of this experiment was intended to assess the ability of a simulated ecosystem to purify TITP effluent biologically. The effluent was initially diluted to a concentration of 32% with sea water, inoculated with wild phytoplankton from the Los Angeles Harbor, and incubated for twelve days to produce the stock solution. This solution was then trickle-fed at various concentrations to a simulated mussel-bed ecosystem. Nutrient samples were taken throughout the experiment to determine the biological purification ability of this system. Only the ammonia values are discussed in the report.

As can be seen from the average ammonia values presented in Table 6 , the initial 32 percent TITP effluent was very high in ammonia. A value of 84.482 μg at/l was found. After the twelve-day incubation period, however, the major portion of the ammonia was removed from the effluent solution. This was probably due to a combination of uptake and evaporation. The stock value prior to the start of trickle feeding (S_o in Table) was only 4.622 μgat/L. This implies a high efficiency of ammonia removal by the phytoplankton in the stock TITP effluent solution. The low ammonia value in the effluent solution was reduced even more by the end of the test, to 1.881 μgat/L (Sc in Table 6). The ammonia removal efficiencies are within the range suggested by Goldman and Ryther (1975) for mass cultures of marine algae. This result implies that the algae by themselves are highly efficient in purifying TITP waste of ammonia.

Since the stock solution ammonia levels are so much lower than for normal harbor sea water (1.8-4.6 mg/L for the former, as opposed to 10.8-11.2 μg at/l in harbor water controls), the only effect that was observed in the final outflows from the troughs was an "ammonia reduction" in the higher concentration of stock TITP solution. The resolution of ammonia analysis was too low to detect significant ammonia removal by the simulated mussel ecosystem.

In summary, the pre-DAF cannery wastes furnished a nutrient source that could be distinguished as beneficial in *Fundulus* tests. *Mercenaria* tests were not judged suitable for short-term tests, due to very slow growth rates.

In flow-through, simulated ecosystem tests, wild phytoplankton cultures reduced ammonia levels greatly. Ammonia levels were further reduced in the flow-through so that the final values were below ambient seawater levels. The polyculture treatment on a small scale suggests optional treatment modes as well as natural biological processes in the harbor.

LITERATURE CITED See Section VIA

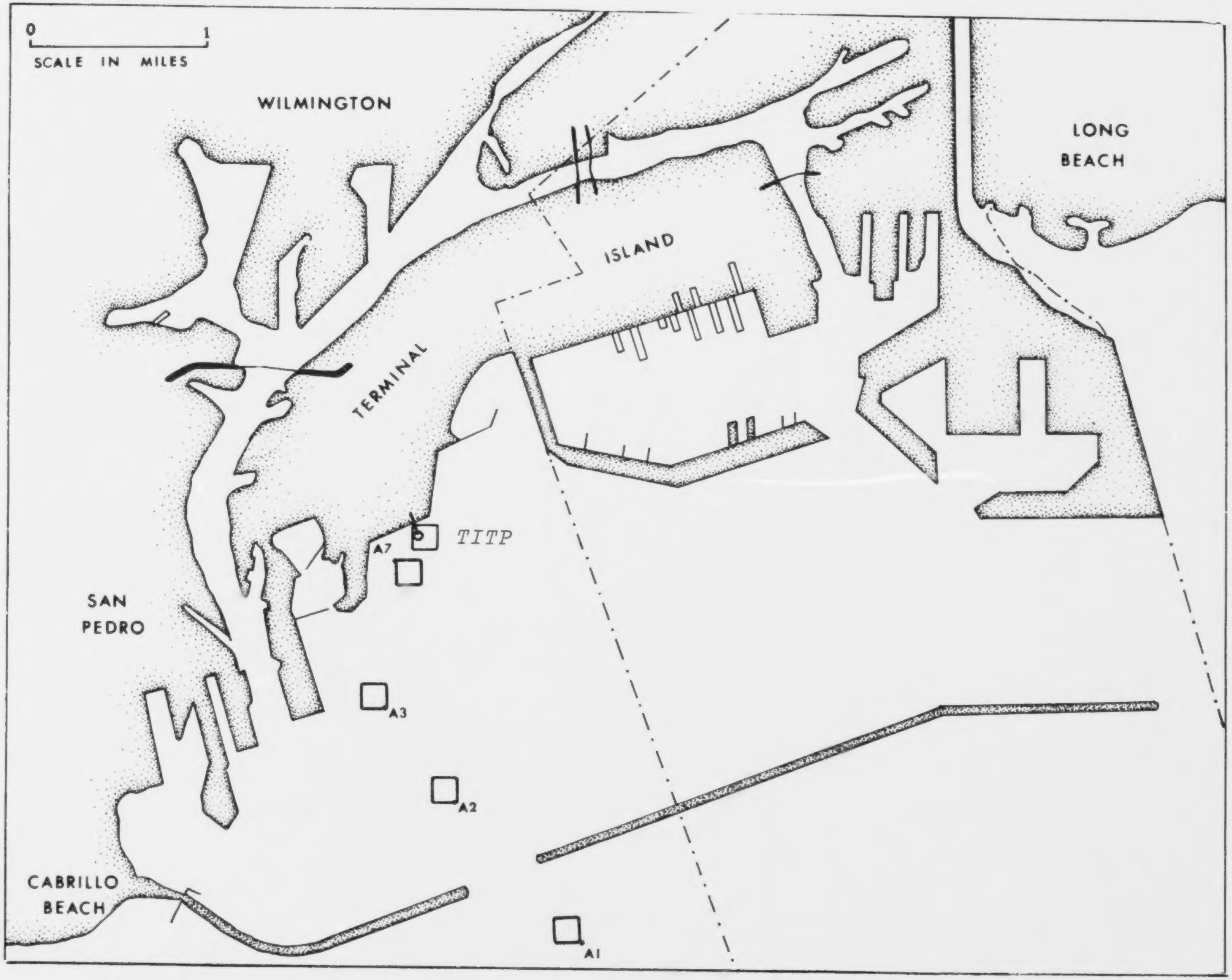


Figure 1. Location of Mussel Racks for Biostimulation in situ Studies.

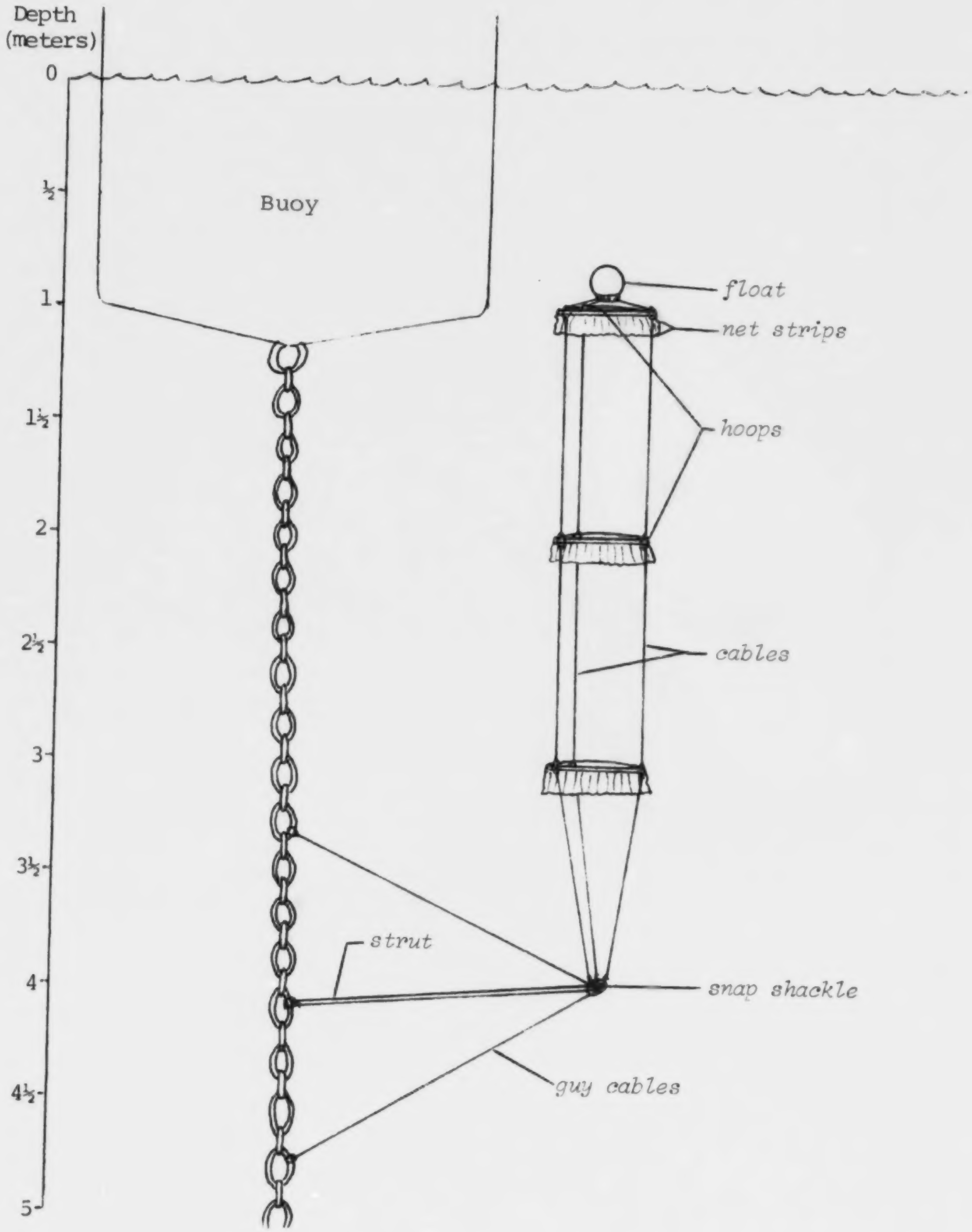
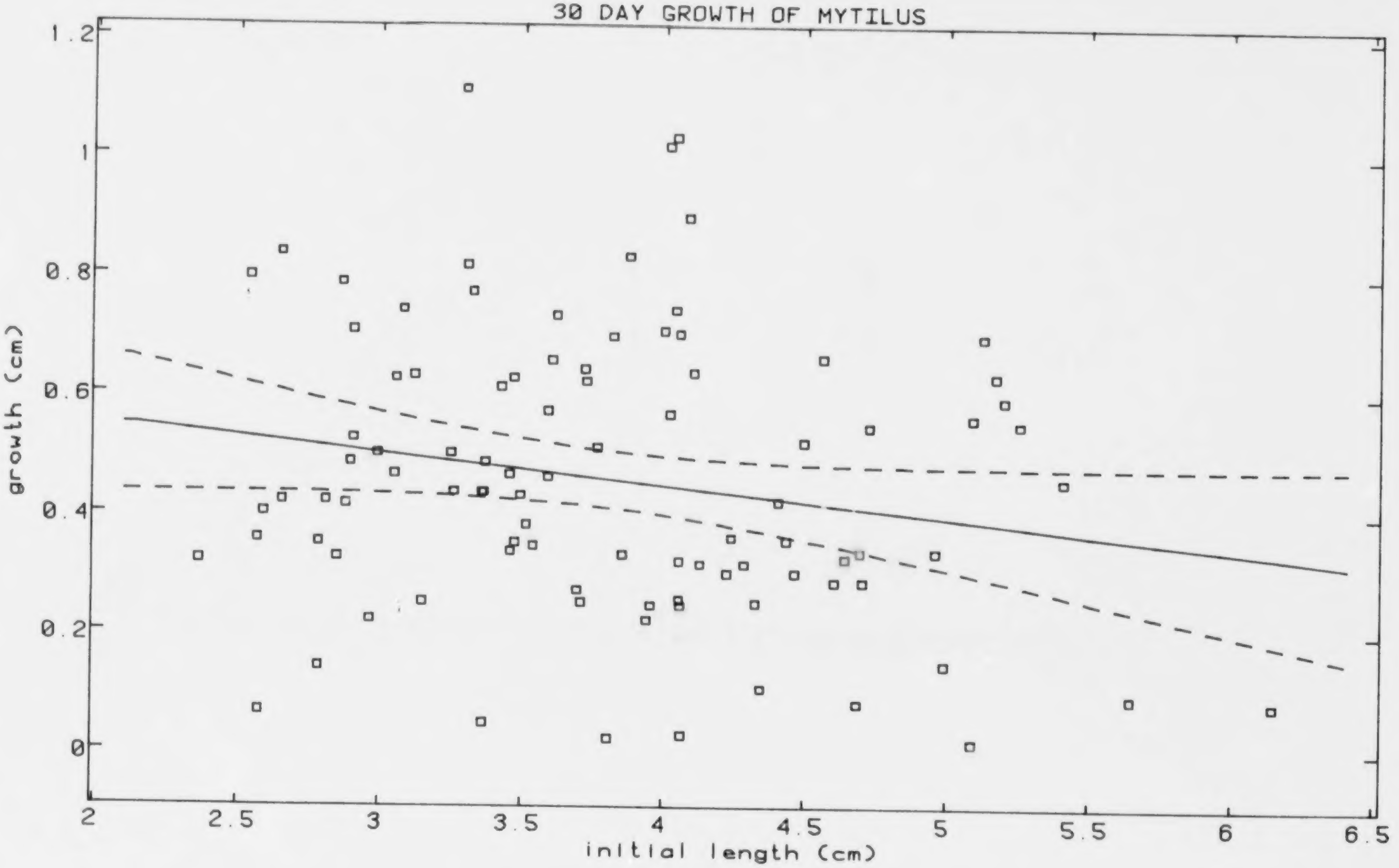


Figure 2. Construction Details for *in situ Mytilus* Bioenhancement Experiment

FIGURE 3. ABSOLUTE GROUP OF MYTILUS EDULIS



30 DAY GROWTH OF MYTILUS

The regression line and 95% confidence limits are plotted with the origional data.

```
TABLE 1.            LINEAR REGRESSION ANALYSIS

30 DAY GROWTH OF MYTILUS, ABSOLUTE GROWTH
--

X represents initial length (cm).
Y represents growth (cm).

For 96 points supplied, the mean of X is 3.8076,
                    and the mean of Y is 0.4557.

The variance of X is 0.6326 and of Y is 0.0562.
--

The regression equation is:  Y= -0.0539 X + 0.6610.

95.0% confidence limits for the slope are -0.1140 & 0.0061.
--

ANALYSIS OF VARIANCE:

SOURCE      SS            df          MS            Fs          P

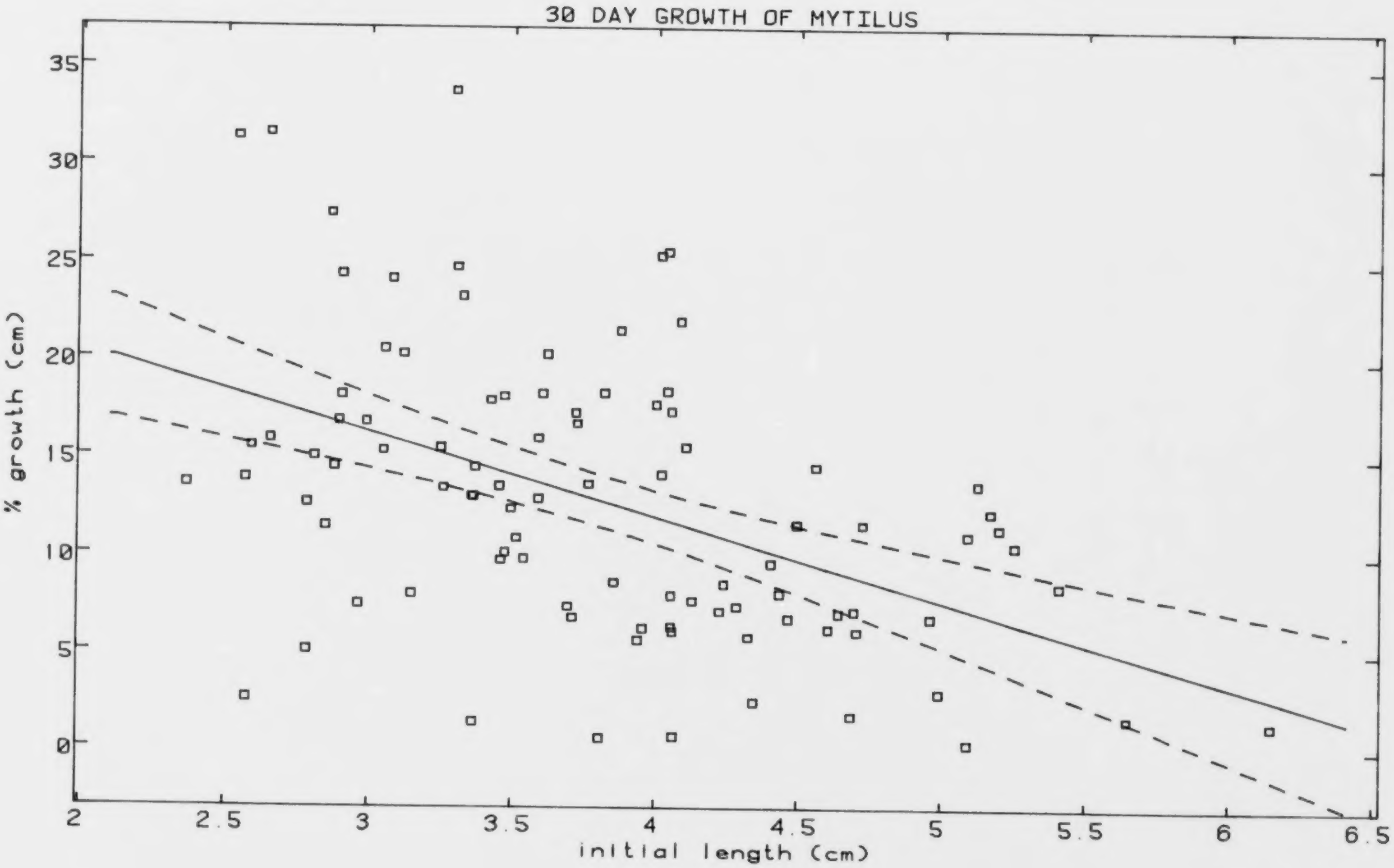
groups      5.3402        95          0.0562
  linear      0.1747        1           0.1747      3.1794      0.078
  dev.        5.1655       94           0.0550

error       0.0000         0          0.0000

total       5.3402        95


                              ----
```

FIGURE 4. PERCENT OF BODY LENGTH GROWTH



The regression line and 95% confidence limits are plotted with the origional data.

TABLE 2. LINEAR REGRESSION ANALYSIS

```
30 DAY GROWTH OF MYTILUS, PERCENT OF BODY LENGTH
--

X represents initial length (cm).
Y represents % growth (cm).

For 96 points supplied, the mean of X is 3.8076,
                    and the mean of Y is 12.6748.

The variance of X is 0.6326 and of Y is 52.7906.
--

The regression equation is:  Y= -4.3020 X + 29.0551.

95.0% confidence limits for the slope are -5.9524 & -2.6516.
--

ANALYSIS OF VARIANCE:

SOURCE     SS            df        MS            Fs          P

groups  5015.1113       95       52.7906
 linear    1112.1590      1      1112.1590      26.7856     0.000
 dev.      3902.9524     94        41.5208

error       0.0000       0         0.0000

total   5015.1113       95
```

TABLE 3. HARTLEY ANOVA

IN SITU MYTILUS BIOENHANCEMENT

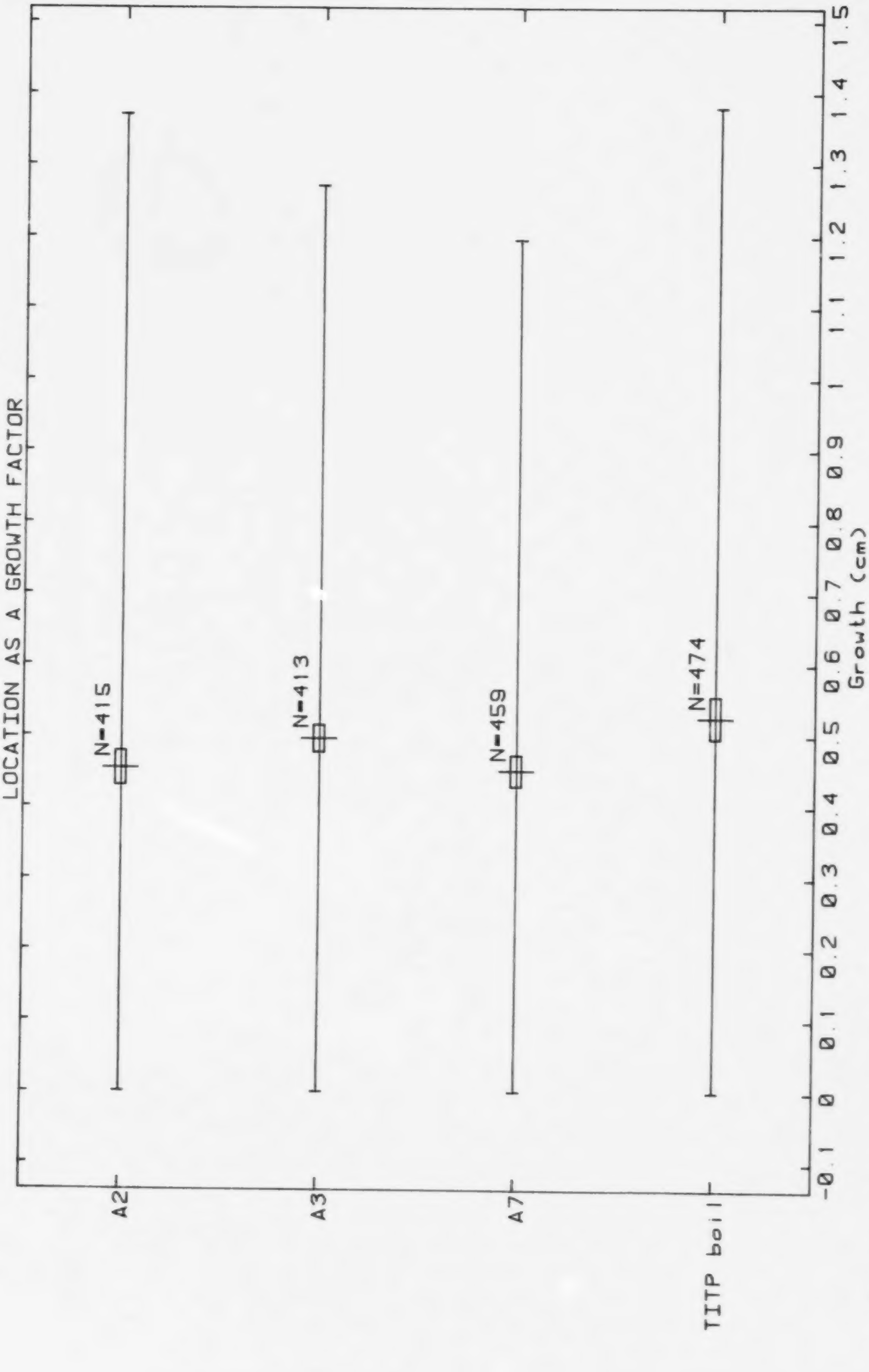
Factors:

A(17) - replicates
B(3) - depth
C(4) - location
D(4) - season

---

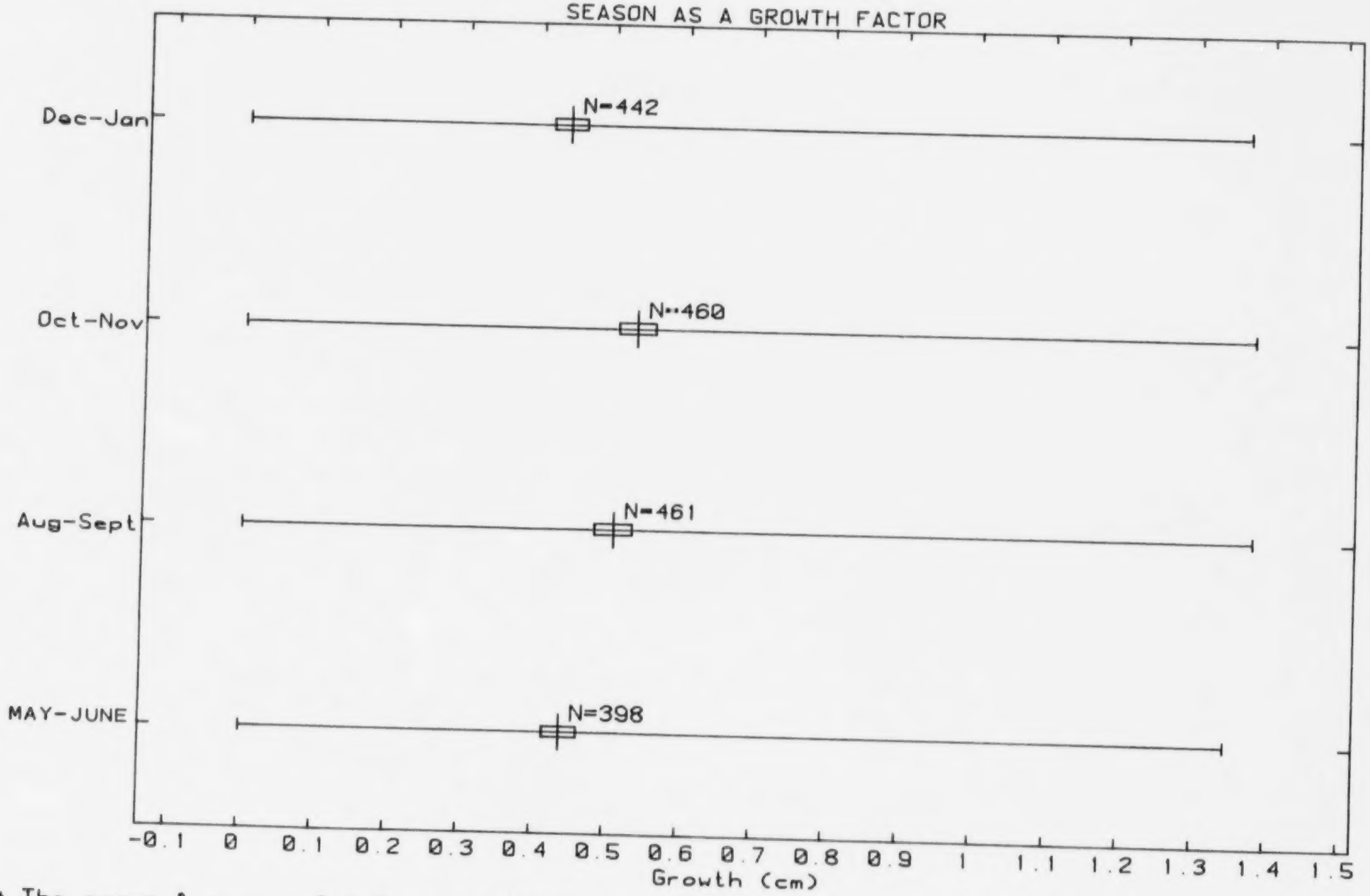
source of variation	sums of squares	degrees of freedom	mean squares
A	0.9788	16	0.0612
B	0.1929	2	0.0964
AB	2.3700	32	0.0741
C	1.6322	3	0.5441
AC	2.9020	48	0.0605
BC	0.7509	6	0.1251
ABC	5.9547	96	0.0620
D	1.9132	3	0.6377
AD	2.7129	48	0.0565
BD	0.5021	6	0.0837
ABD	7.6778	96	0.0800
CD	1.5481	9	0.1720
ACD	9.5763	144	0.0665
BCD	1.7497	18	0.0972
ABCD	18.5400	288	0.0644

FIGURE 5. MYTILUS EDULIS GROWTH WITH LOCATION AS A GROWTH FACTOR



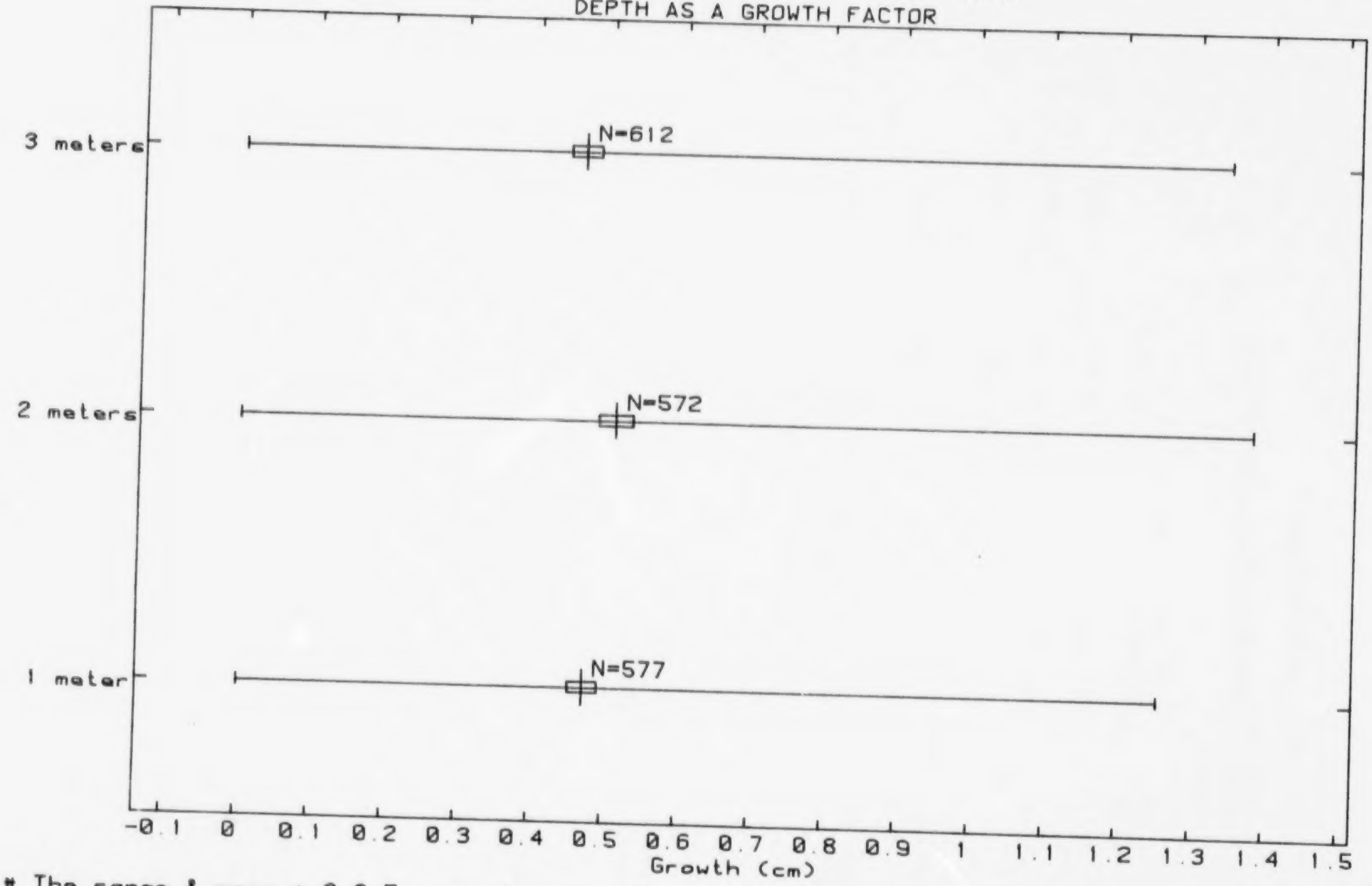
* The range & mean ± 2 S.E. are shown.

FIGURE 6. MYTILUS EDULIS GROWTH WITH SEASON AS A GROWTH FACTOR



* The range & mean ± 2 S.E. are shown.

FIGURE 7. MYTILUS EDULIS GROWTH WITH DEPTH AS A GROWTH FACTOR



* The range & mean ± 2 S.E. are shown.

TABLE 4.

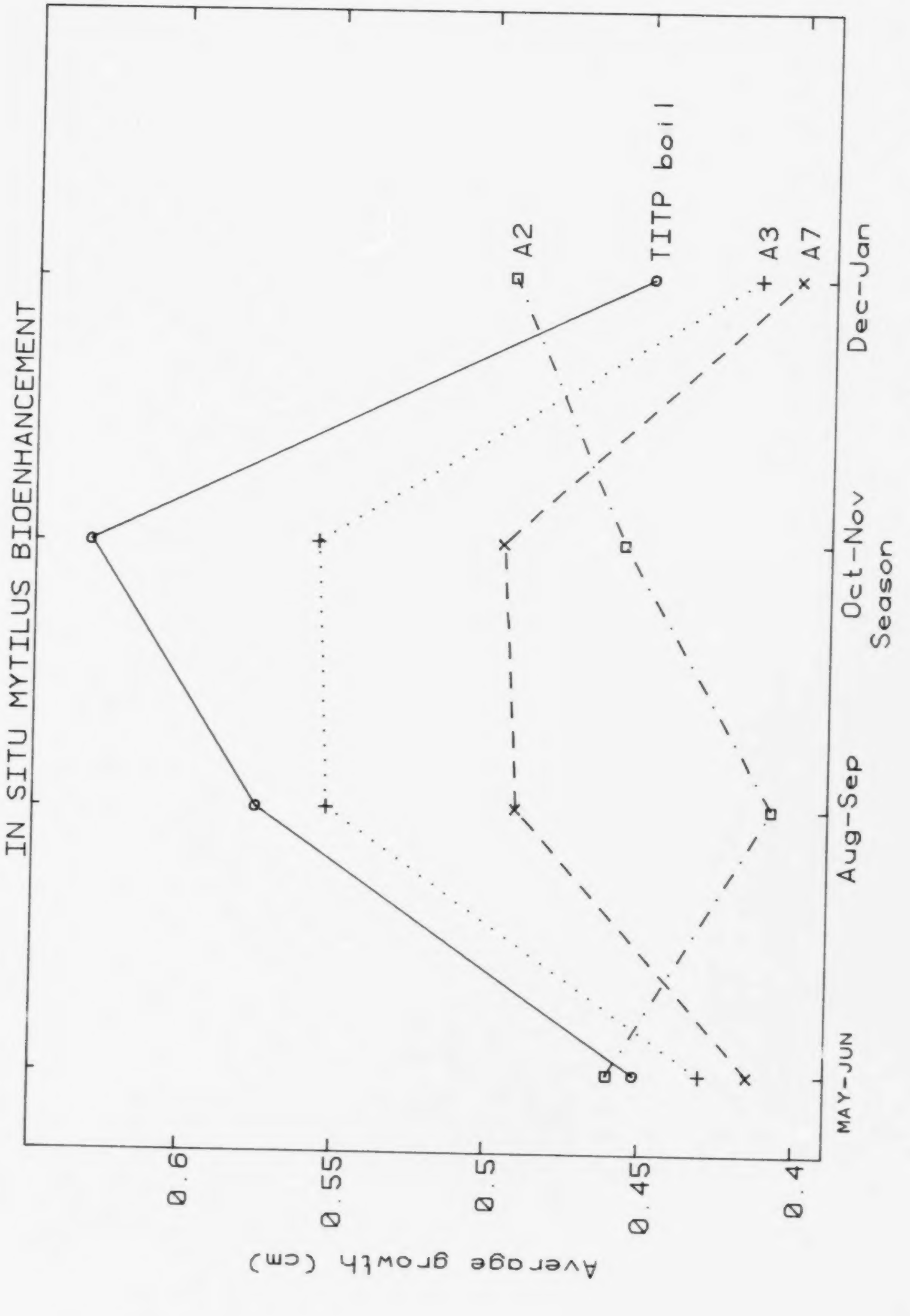
IN SITU MYTILUS BIOENHANCEMENT

ANOVA TABLE - 3 FACTORS WITH REPLICATES.

SOURCE OF VARIATION	SUMS OF SQUARES	DF	MEAN SQUARES	F_S	P
SEASON	1.9132	3	0.6377	9.6577	<<.001 **
LOCATION	1.6322	3	0.5441	8.2402	<<.001 **
DEPTH	0.1929	2	0.0964	1.4599	>.20
LOCATION & SEASON	1.5481	9	0.1720	2.6048	<.006 *
DEPTH & SEASON	0.5021	6	0.0837	1.2676	>.25
DEPTH & LOCATION	0.7509	6	0.1251	1.8946	>.05
ALL 3	1.7497	18	0.0972	1.4721	>.05
WITHIN GROUPS (ERROR)	50.7125	768	0.6603		

CONCLUSION: SEASON AND LOCATION AND THEIR INTERACTION ARE THE ONLY SIGNIFICANT (P<.05) FACTORS.

FIGURE 8.


IN SITU MYTILUS BIOENHANCEMENT
Average growth (cm)
0.4
0.45
0.5
0.55
0.6
MAY-JUN
Aug-Sep
Oct-Nov
Dec-Jan
Season
A2
TITP boil
A3
A7

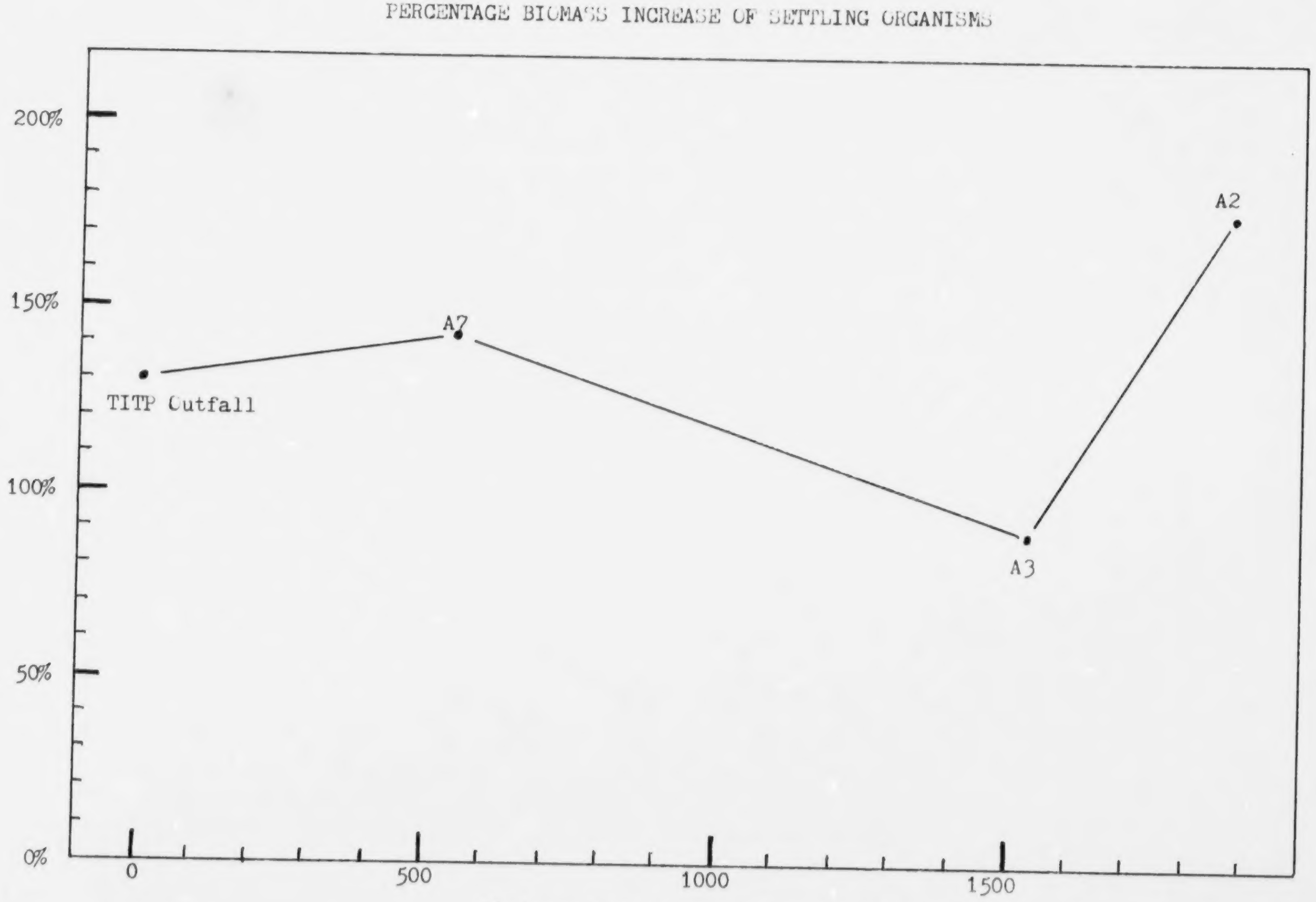


FIGURE 9. Percentage biomass increase of settling organisms in the proximity of the TITP outfall during the one month period from July 14 - Aug 14, 1978.

TABLE 5, SETTLING RACK BIOENHANCEMENT STUDY DATA

Settling Rack #	Weight Initial	Location 1st Month	Weight 1st Month	Biomass 1st Month	Location 2nd Month	Weight 2nd Month	Biomass 2nd Month	% Increase of Biomass
1	17 1/4 oz	A2	28 oz	10 3/4 oz	TITP boil	42 oz	24 3/4 oz	130%
2	18 3/4 oz	A2	30 oz	11 1/4 oz	A7	46 oz	27 1/4 oz	142%
3	18 oz	A2	27 1/2 oz	9 1/2 oz	A3	36 1/2 oz	18 1/2 oz	95%
4	18 1/2 oz	A2	27 oz	8 1/2 oz	A2	42 oz	23 1/2 oz	177%

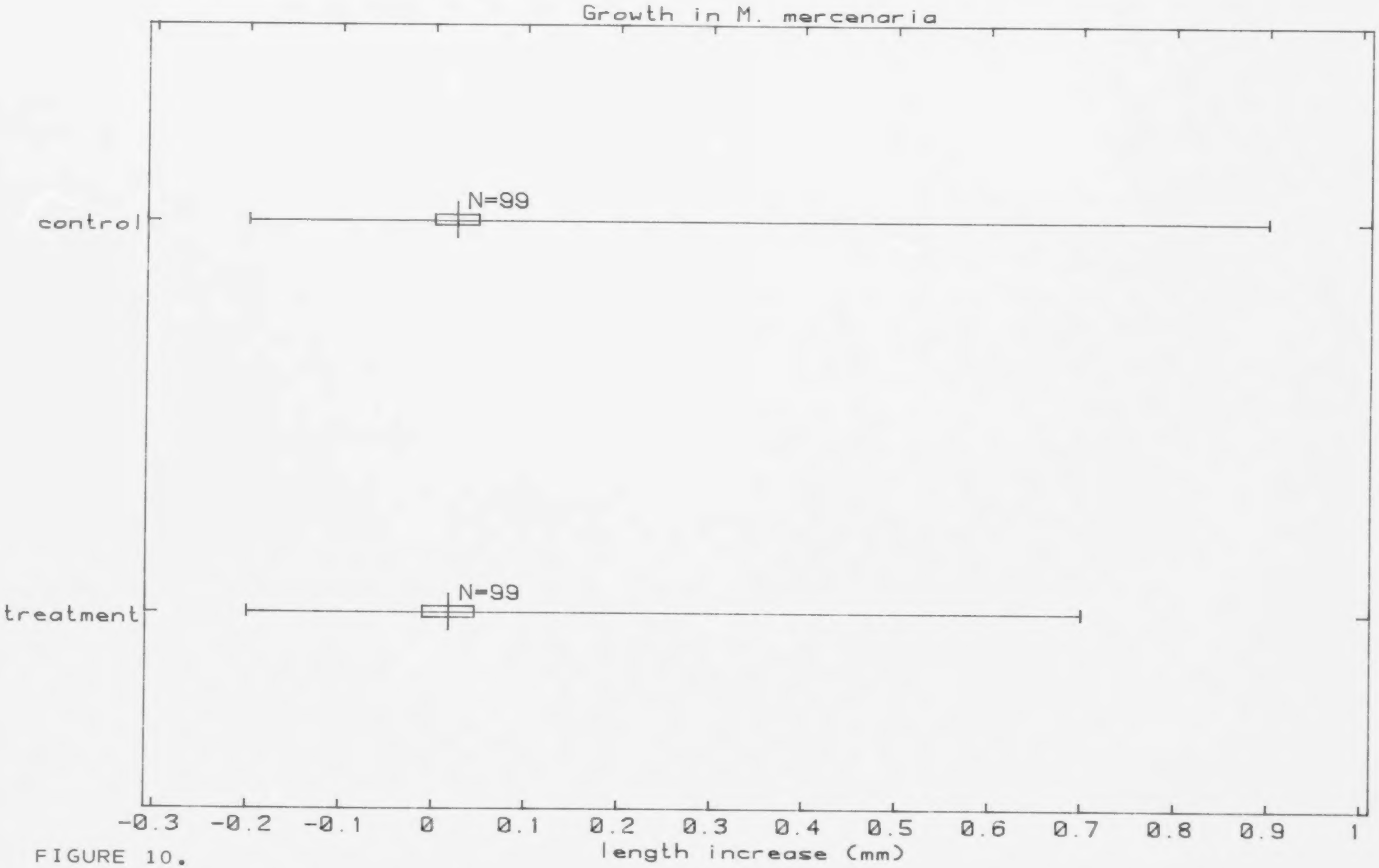


FIGURE 10.

* The difference is not significant (by anova, P= 0.722); Range & mean ± 2 S.E. are shown. Homogeneity of variances requirement realized without transformation. (C=0.5715).

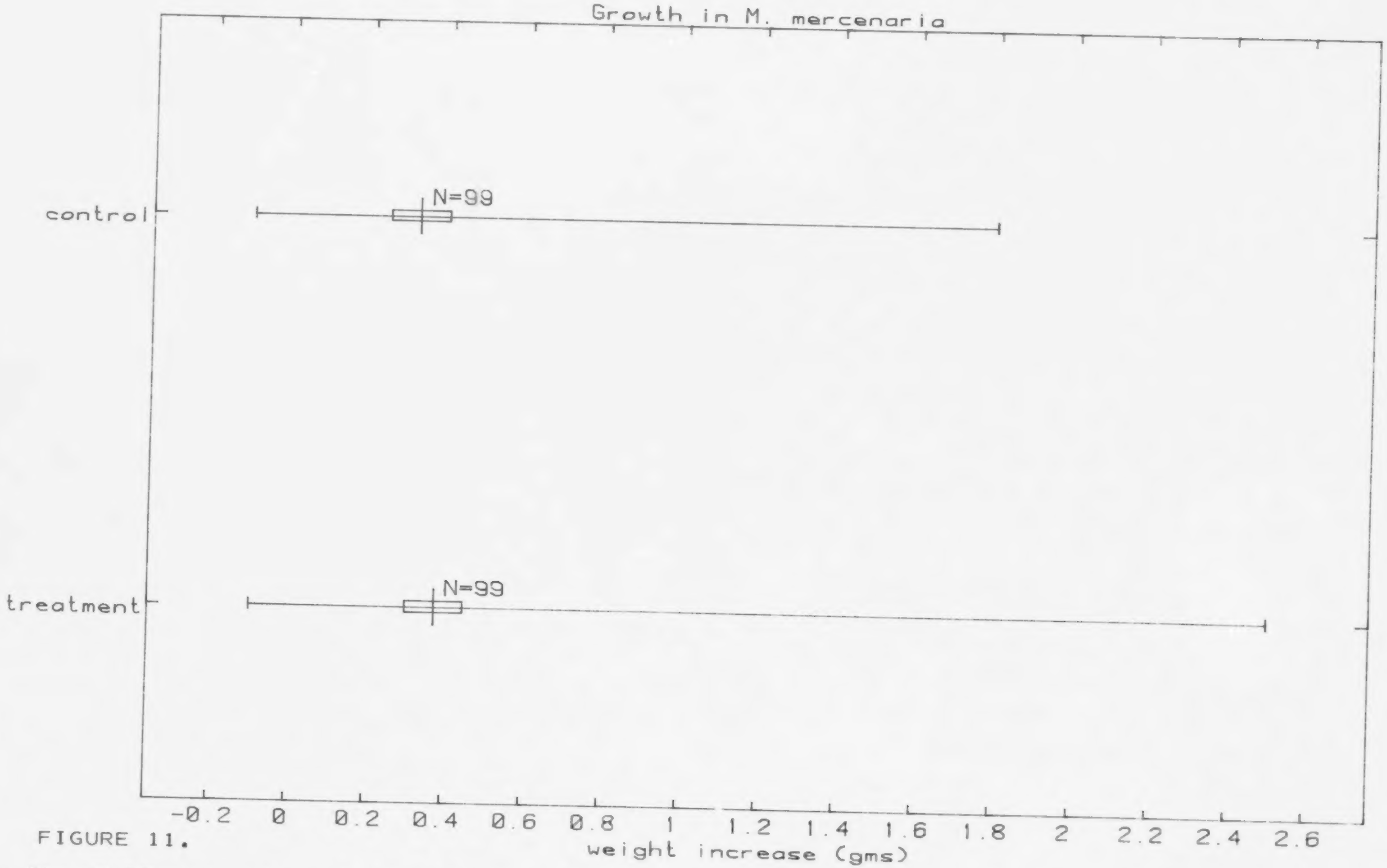


FIGURE 11.

* The difference is not significant (by anova, P= 0.340); Range & mean ± 2 S.E. are shown. Homogeneity of variances requirement realized without transformation. (C=0.5027).

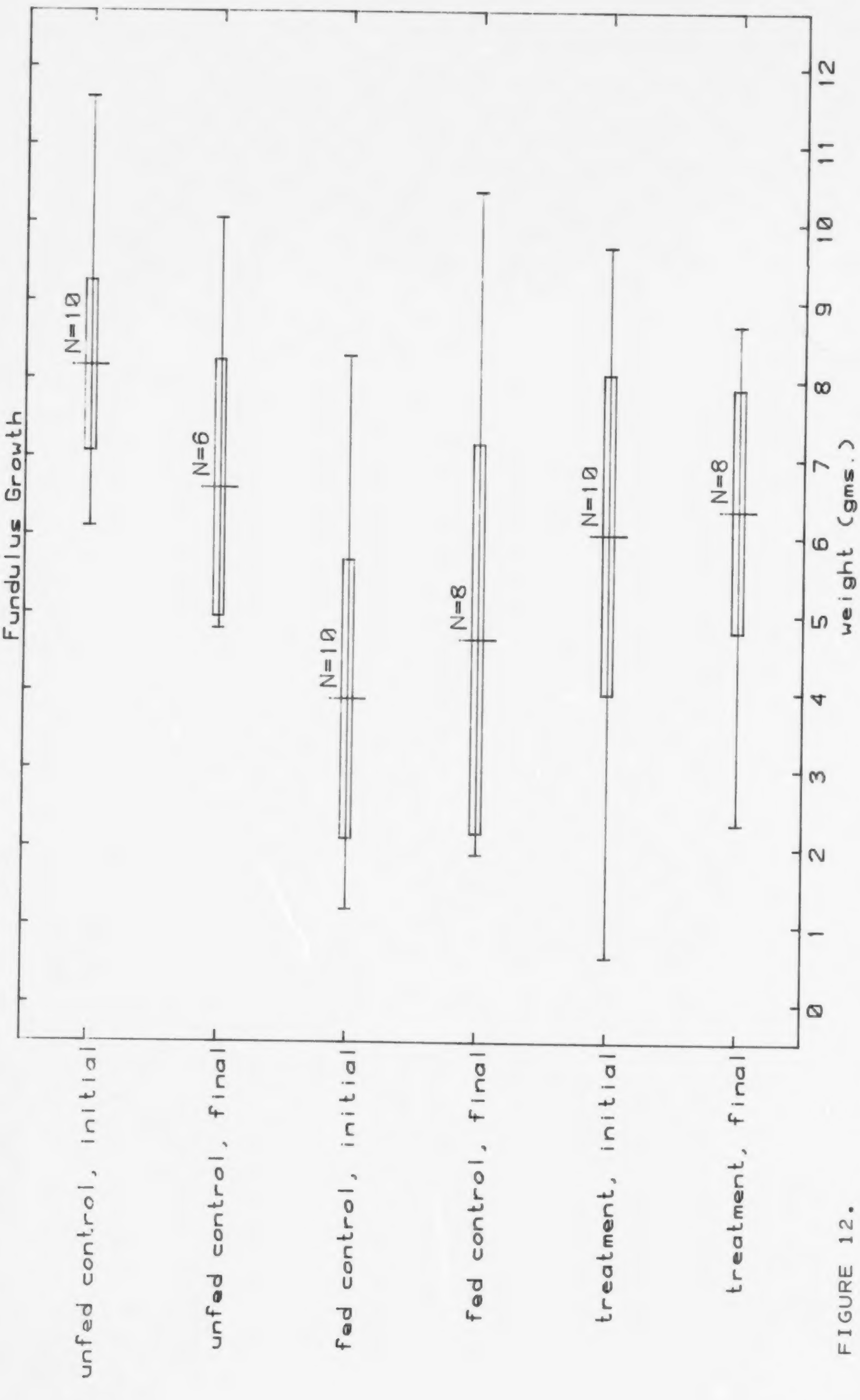


FIGURE 12.

* The difference is significant (by anova, P= 0.022); Range & mean ± 2 S.E. are shown. Homogeneity of variances requirement realized without transformation. (C=0.2917).

TABLE 6 . AVERAGE AMMONIA VALUES FOR THE FLOW-THROUGH BIOENHANCEMENT STUDY (VALUES IN µg AT NH_3/L)

CONC. OF 2° EFFLUENT	ELAPSED TIME INITIAL	2 HRS	5 HRS	6 HRS	FINAL
CONTROL (0%)	10.8825	10.533	11.178	10.748	11.205
1.35%	10.318		10.399	9.996	11.125
5.68%	10.452	10.184	10.318	9.861	9.512
10%	10.238	7.980	8.249	9.861	12.360

STOCK SEWAGE SOLUTION AMMONIA VALUES

INITIAL TITP	84.482
SO	4.622
SX	1.881
AMBIENT HAROR WATER	10.8-11.2

ALL VALUES GIVEN ARE THE AVERAGE OF THREE REPLICATE SAMPLES.

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EAP

ECOLOGICAL ANALYSIS PACKAGE

METHODS SECTION

****** DISCRIMINANT ANALYSIS ******

PAPER #1

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INTRODUCTION

There are two basic approaches in discriminant analysis. Both involve a priori definition of two or more groups of observations. The most common use of discriminant analysis involves assigning unknown observations to one of the defined groups (Lachenbruch, 1975; Gnanadesikan,1977). The second approach involves the description and testing of between-group differences (Hope, 1969; Cooley and Lohnes, 1971; Green, 1976; Pimentel and Frey, 1978). The latter approach is discussed here.

Quite often in ecological-survey work, one of the goals is to study the relationships between the biological and environmental patterns. As will be shown, discriminant analysis is well suited for this purpose.

The general idea of discriminant analysis is illustrated with an example. Fig 1A shows a dendrogram defining two groups of sampling sites. It is assumed that this cluster analysis is based on the biotic data collected at the sites . This would be one way to summarize the biological patterns in the study area.

Let's say two environmental variables (salinity and depth) are also measured at each site. Fig 1B shows what might result if the sites were plotted according their level of salinity and depth. Note the following.

1) All sites in dendrogram group 1 (sites A-E) are found in shallow depths.

2) All sites in group 2 (sites F-L) are found in deeper depths.

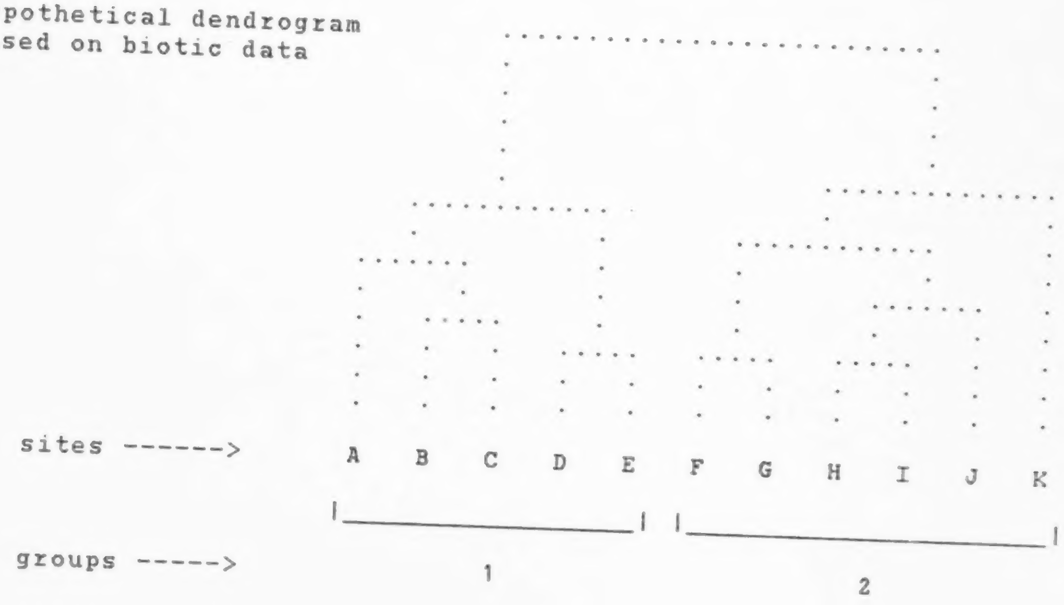
3) The salinity values found at the sites in the groups are broadly overlapping.

With this type of result, displayed in this manner, it is evident that the biological pattern may somehow be related to variations in depth, and probably not related to the level of salinity found at the sites.

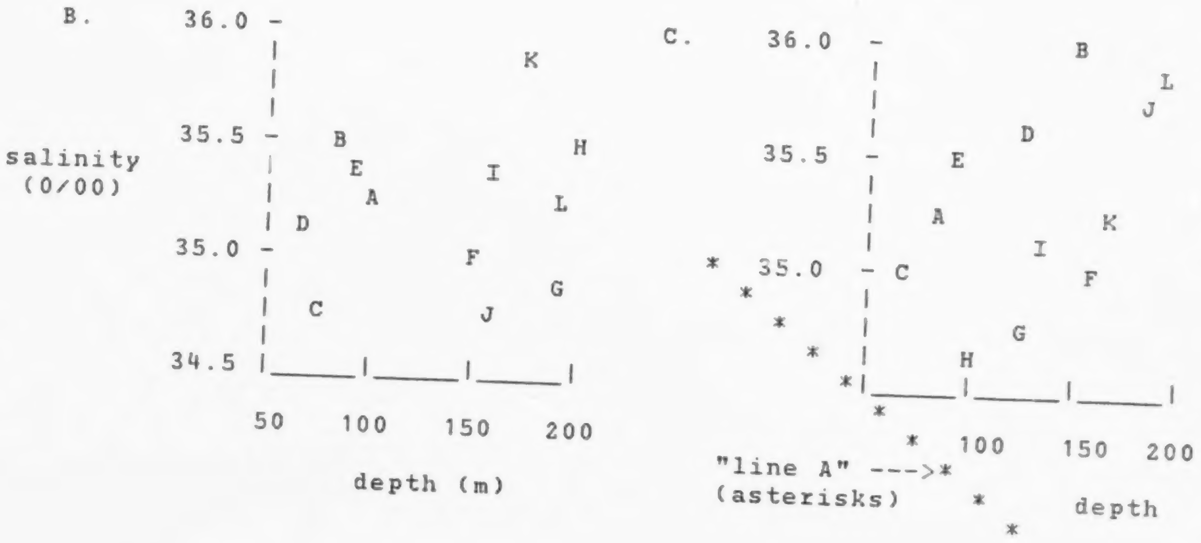
Fig 1C illustrates a more complex hypothetical result. Again, the sites are plotted according to the depth and salinity values. However, the values of both variables are broadly overlapping, i.e., sites in both groups are found more or less at all measured values of depth and salinity. In spite of this, the group members are completely separated in this plot, indicating that these two variables may somehow be related to the group separation.

Figure 1. Hypothetical survey data used to explain the idea of discriminant analysis.

A. hypothetical dendrogram based on biotic data



environmental parameters at the sites



If all points in the plot (fig 1C) were perpendicularly projected onto "line A", the point projections for the two groups would be completely separated. In effect, a new variable which separates the groups has been defined. The values of this variable are the values of the projections onto the diagonal line. Projections onto the line will be correlated with the values of both salinity and depth. This new variable could be thought of as a "salinity-depth considered simultaneously"-type parameter. The conclusion to be drawn from fig 1C would be that the group separation (biotic pattern) could be related to both salinity and depth, but to account for the result, both variables must be considered simultaneously.

In fig 1B, note that if a "new variable" which would best separate the groups were to be defined in the same manner as in fig 1C, the position of the line representing the variable would lie parallel or nearly parallel to the depth dimension. Thus, the new variable would essentially be a depth variable, with little, if any, component of salinity.

THE METHOD OF DISCRIMINANT ANALYSIS IN GENERAL TERMS

Discriminant analysis attempts to find these "new variables" which will best separate the predefined groups. In general terms, the process can be summarized as follows.

1) A priori groups are defined according to a biological criterion.

2) A hypotetical, multidimensional "space" is set up. The dimensions of this space represent the measured environmental variables. The position of a site (sample, observation, etc.) will depend on the level of each variable measured at the site.

3) A new variable, which best separates the groups, is defined. This variable is represented in the space by a line called a discriminant axis (e.g., "line A" in fig 1C). The value of this new variable at a site is the perpendicular projection of the site point onto the discriminant axis (see fig 2). The value of the projection is called a discriminant score.

4) The position of the discriminant axis in this space will depend on which combination of variables best separates the groups. The discriminant axis will not extend far into dimensions which represent variables showing little relationship to group separation (e.g., salinity in fig 1B). The discriminant axis will be situated mostly in dimensions representing variables which are related to group separation (e.g., depth in fig 1B, or both depth and salinity in fig 1C).

5) When more than two groups have been defined, more than one discriminant axis may be required to separate the groups. Fig 3 illustrates this concept. Note that the first discriminant axis separates group Y from groups X and Z, while the second axis separates group Z from groups X and Y. To avoid redundancy of information on the different axes, the site scores on the different axes are made to be uncorrelated. The axes are not necessarily at right angles to each other (Green, 1976). The axes are usually ordered according to the amount of group separation accounted for, i.e., the first axis will show the most group separation, the second axis, the second most, and so on.

Figure 2. An illustration of the idea of scores as perpendicular projections of points onto the discriminant axis.

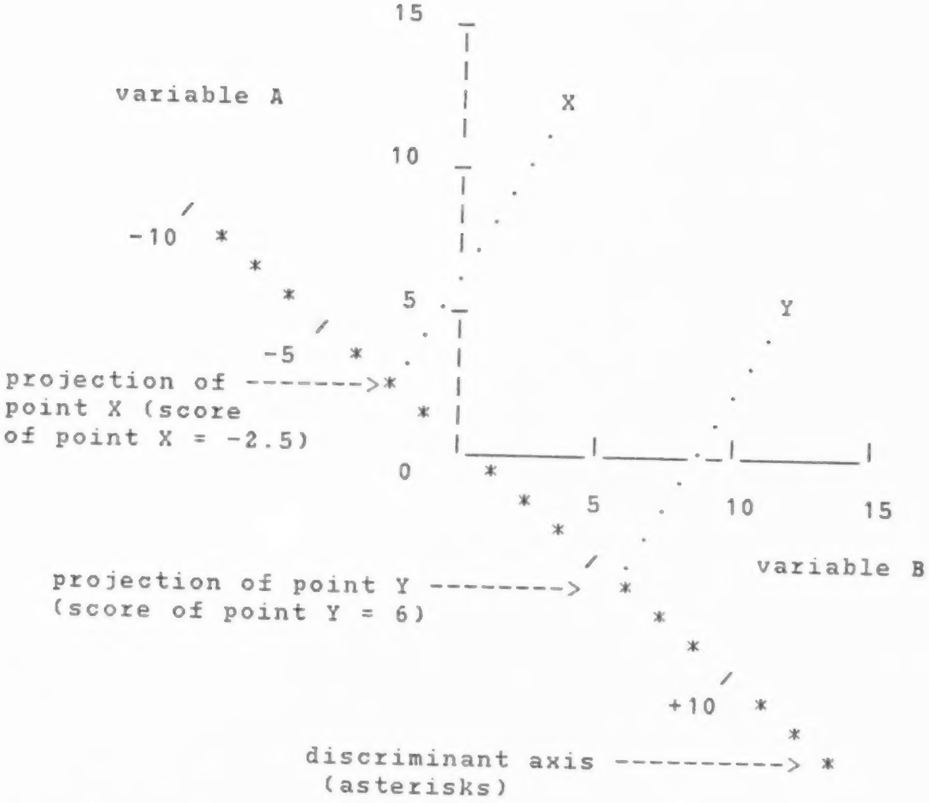
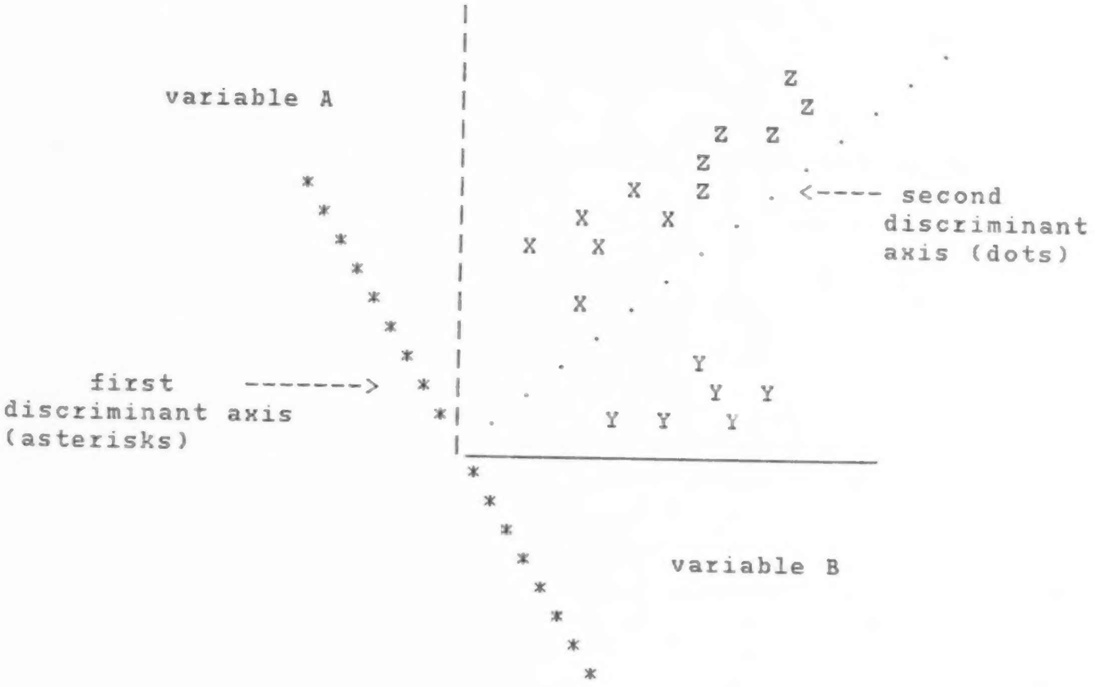


Figure 3. Discriminant analysis with three groups (X,Y,Z). Notice that two discriminant axes are required to separate the three groups.


variable A
variable B
first discriminant axis (asterisks)
second discriminant axis (dots)
X
Y
Z

DISCRIMINANT COEFFICIENTS

Discriminant coefficients are used to indicate which original variables are related to each axis. Each axis has a separate set of coefficients, with one coefficient for each original variable. The magnitude of the absolute value of a coefficient is relative to the importance of the corresponding variable on the axis in question. For example, if the data in fig 1B were analyzed, the coefficients would appear as

	axis 1
salinity	0.7
depth	99.3

The coefficients from the data in fig 1C would appear as

	axis 1
salinity	36.2
depth	63.8

These results agree with the observations made above, mainly that depth was mostly related to group separation in fig 1B, and both variables were related to group separation in fig 1C.

The coefficients are adjusted to account for the differing scales of the original variable. There are three methods by which this is accomplished. One is to standardize the coefficeints for a variable by the total standard deviation for that variable (Cooley, and Lohnes, 1971). The second is to standardize the coefficients by the within-group standard deviation of the the corresponding variables (Green, 1976). The third technique involves the the computation of the coefficients of separate determination (Hope, 1969). These coefficients are already adjusted for scale, and no standardization is required. The coefficients given in the above examples are coefficients of separate determination.

MULTIVARIATE VS. UNIVARIATE METHODOLOGY

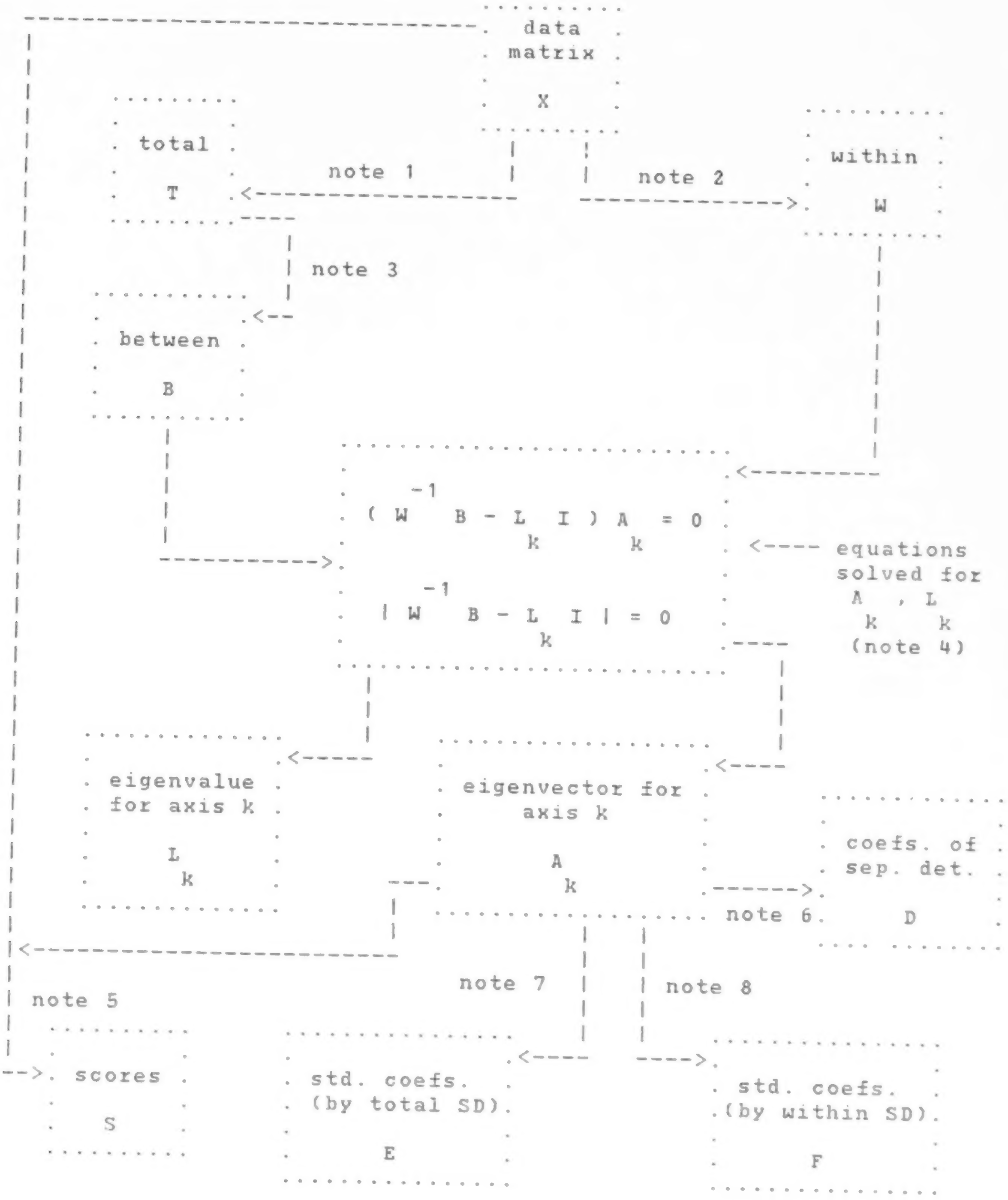
The example used in fig 1C illustrates the importance of using a multivariate technique in such cases. A multivariate technique considers all the variables simultaneously instead of one at a time as in univariate analysis.

To illustrate the increased power of the multivariate method, univariate F tests (one-way ANOVA) were run to try to detect group differences in each of the two variables (data from fig 1C). Neither F value was significant at the 5% level. In contrast, the discriminant-analysis test for group differences (see note 9, fig 4) was highly significant (P << .001). The latter result, of course, is the desired one, since there are group differences in relation to the variables.

DISCRIMINANT ANALYSIS CALCULATIONS

No attempt is made here to completely explain the discriminant analysis calculations. The reader should consult the multivariate texts mentioned above (especially, Green, 1976) for more details. Fig 4 summarizes the calculations. Matrix notation is used. There are v variables and n observations (sites, etc.). Sample calculations are shown in Appendix A.

Figure 4. Flow chart of the discriminant analysis calculations. See accompanying notes for additional details.



NOTES FOR FIGURE 4.

********** note 1 **********

The data are centered by the overall variable mean. If Z is the centered data matrix, then

$$z_{kj} = x_{kj} - \bar{x}_j \quad ,$$

with

$$\bar{x}_j = \frac{\mathrm{SUM}_{i=1}^{n}(x_{ij})}{n} \quad .$$

The T matrix is calculated from Z as follows.

$$T = Z' Z \quad .$$

The element in the kth row and the jth column of T would be

$$t_{kj} = \mathrm{SUM}_{i=1}^{n} (z_{ik} \; z_{ij}) \quad .$$

or, in terms of X,

$$t_{kj} = \mathrm{SUM}_{i=1}^{n} ((x_{ik} - \bar{x}_k)(x_{ij} - \bar{x}_j)) \quad .$$

Matrix T is symmetrical.

NOTES FOR FIGURE 4.

************* note 2 **************

The data for each predefined group are worked on separately. Define Y_h as a (m x v) data matrix containing the observations in group h. The data are centered by the variable means for the group h. If C_h is the centered matrix for group h, then

$$c_{kjh} = y_{kjh} - \bar{y}_{jh} \quad .$$

The calculation of the w matrix for group h is as follows.

$$W_h = C'_h C_h \quad .$$

The element in the kth row and the jth column of W_h is

$$w_{kjh} = \mathrm{SUM}_{i=1}^{m_h} (c_{ikh} c_{ijh}) \quad ,$$

or in terms of Y,

$$w_{kjh} = \mathrm{SUM}_{i=1}^{m_h} ((y_{ikh} - \bar{y}_{ih})(y_{ijh} - \bar{y}_{jh})) \quad .$$

(note 2 continued on next page)

NOTES FOR FIGURE 4.

(note 2, continued)

To obtain the final W matrix, the W_h matrices for each group are summed, i.e.,

$$W = W_1 + W_2 + \ldots\ldots W_g \quad ,$$

where g = the number of groups. This pooled matrix summarizes the within-group variation and covariation.

Matrix W is symmetrical.

*************** note 3 ***************

The simplest way to obtain matrix B is as follows:

$$B = T - W$$

The element in the kth row and the jth column of B is equivalent to

$$b_{kj} = \sum_{h=1}^{g} (n_h (\bar{x}_{kh} - \bar{x}_k)(\bar{x}_{jh} - \bar{x}_j)) \quad ,$$

where g is the number of groups, n_h is the number of observations in group h, $\bar{x}_{kh}$ is the mean of variable k in group h, $\bar{x}_{jh}$ is the mean of variable j in group h, and $\bar{x}_k$ is the over-all mean of variable k, and and $\bar{x}_j$ is the overall mean of variable j. This matrix summarizes the variation and covariation of the group means.

NOTES FOR FIGURE 4.

*************** note 4 ****************

The eigenvalues and eigenvectors of the asymmetric matrix $W^{-1}B$ are found. The solutions for these equations will have the following property.

$$L_k = \left. \frac{A'_k B A_k}{A'_k W A_k} \right|_{MAX} ,$$

where L_k is the eigenvalue for axis k, and A_k is the eigenvector for axis k. In words, this means that the eigenvalue of axis k is equal to the maximized ratio of 1) the between-group sum of squares of the discriminant scores, and 2) the within-group sum of squares of the discriminant scores for axis k. This maximization will emphasize variables which contribute a relatively large amount of between-group variability relative to the within-group variability.

This maximization is constrained in that

$$A'_k A_k = 1 ,$$

i.e., each eigenvector must be of unit length. This avoids a solution which makes $A'_k B A_k$ (or $A'_k W A_k$) indefinitely large (or small) by making the entries of A_k arbitrarily large (or small). A derivation of these equations is found in Green (1976; 247-254).

NOTES FOR FIGURE 4.

**************** note 5 *****************

The scores on axis k (S_k) are calculated as follows.

$$S_k = X A_k .$$

S_k will be the kth column in matrix S, which contains the scores for all p axes. The scores for each axis can be standardized to unit variance by dividing the eigenvector elements by the overall standard deviation of the corresponding variable, i.e.,

$$p_{ik} = a_{ik} / q_k^{1/2} ,$$

where a_{ik} is the eigenvector element for variable i on axis k, and

$$q_k = A'_k (\frac{1}{n-1} T) A_k$$ (Cooley and Lohnes, 1971; 31,247).

P_k would be used in subsequent calculations instead of A_k.

NOTES FOR FIGURE 4.

************** note 6 ***************

The coefficients of separate determination for axis k are calculated as follows:

$$D_k = Z_k T Z_k U \qquad \text{(Hope, 1969)},$$

where Z_k is a diagonal matrix with the elements of A_k in the principal diagonal, and zeros elsewhere. The matrix U is a (v x 1) column vector of ones. D_k is the kth column of matrix D (D contains the coefficients for all p axes, with axes in the columns).

Theoretically, all the coefficients should be positive. This, however, is not always the case. Experience has shown that the magnitude of the absolute value corresponds to the importance of the variable. The coefficients can be expressed as percents of the total of the coefficients for the axis (only the absolute values used)

*************** note 7 *****************

These coefficients are calculated as follows:

$$e_{jk} = a_{jk} (t_{jj} / (n-1))^{1/2} ,$$

where e_{jk} is the standardized coefficient for variable j on axis k, a_{jk} is the eigenvector element for variable j on axis k, t_{jj} is the jth diagonal element in matrix T (the centered, overall sum of squares of variable j), and n is the total number of observations. The second term in the product standardizes a_{jk} to make all coefficients comparable (the variables will usually be measured on different scales). The coefficients can be expressed as the percent of the total of the absolute values of the coefficients for an axis.

NOTES FOR FIGURE 4.

*************** note 8 ****************

These coefficients are calculated as follows:

$$f_{jk} = a_{jk} (w_{jj} /(n-g))^{1/2} ,$$

where f_{jk} is the standardized coefficient for variable j on axis k, a_{jk} is the eigenvector element for variable j on axis k, w_{jj} is the jth diagonal element in matrix W (the centered, within-group sum of squares of variable j), n is the total number of observations, and g the number of groups. The second term in the product standardizes a_{jk} to make all coefficients comparable (the variables will usually be measured on different scales). The coefficients can be expressed as the percent of the total of the absolute values of the coefficients for an axis.

*************** note 9 ***************

The significance of group separation on axis k can be tested by calculating

$$\text{chi square} = (n-1-1/2(v+g)) \ln(1+L_k) ,$$

with

$$D.F. = v + g - 2 k \qquad \text{(Hope, 1969; 118).}$$

here n = # observations, v = # variables, g = # groups, L_k = eigenvalue for axis k, and ln = a natural log operation. The assumptions of the test are summarized in Green (1971). In addition, the groups must be non-overlapping (Green, 1976; 278). In the author's experience, the assumptions are rarely met with ecological-survey data, but under certain conditions the test may be fairly robust (see pp 33-34). Observation of score plots for the sampling sites will usually be sufficient to determine whether the groups are well separated or not.

THE SELECTION OF GROUPS PRIOR TO THE DISCRIMINANT ANALYSIS

Groups can be chosen in any way relevant to the analyst. One such method has been mentioned in the introduction, i.e., a classification (cluster) analysis prior to the discriminant analysis (Smith, 1976; Green, 1977; Bernstein et al, 1978). Smith (1976; 142-145) discusses some aspects of group selection with hierarchical classification. It is concluded that it may not always be too critical at which specific level the groups are delimited.

An alternate technique for forming groups of observations is to use the species data matrix directly (Green, 1971,1974; James, 1971; Dueser and Shugart, 1978). This technique is illustrated in fig 5. Here each group corresponds to a single species. The variables which tend to correspond with species separation (in space, time, etc.) will be emphasized in the discriminant analysis results. Note that a single observation (site) may be in more than one group. This violates one of the assumptions of the chi-square test for group separation (see note 9 for fig 4).

Figure 5. The formation of groups directly from the biotic data matrix.

A. data matrix

		sites				
		1	2	3	4	5
	A	3	1	0	0	2
species	B	2	0	0	2	1
	C	0	0	3	2	0

B. sites in groups representing each species, i.e., the site in which each species occurs.

	sites in group
A	1, 2, 5
B	1, 4, 5
C	3, 4

WEIGHTED DISCRIMINANT ANALYSIS

It will often be the case that group members will vary in how representative they are of their own group. Weighted discriminant analysis allows for weighting the calculations for a group to give more emphasis to the "better" members of the group in question (Smith, 1976). As will be shown, this technique can also be used to input (into the calculations) information concerning between-group biological similarities. This can significantly increase the power and accuracy of the analysis. It will also be shown that this technique can even be used without any a priori group definition.

Weighted discriminant analysis calculations.

The only changes in the calculations involve the sums of squares and cross-product matrices. Both weighted and unweighted calculations are included for contrast. Sample calculations are shown in Appendix B.

W matrix. In fig 4 (note 2) it was shown that for regular discriminant analysis, the element in the kth row and the jth column of W_h (the contribution of group h to the pooled w matrix) was

$$w_{kjh} = \mathrm{SUM}_{i=1}^{m_h} \left(\left(y_{ikh} - \bar{y}_{kh} \right)\left(y_{ijh} - \bar{y}_{jh} \right) \right) .$$

The weighted calculations are

$$w_{kjh} = \mathrm{SUM}_{i=1}^{m_h} \left(\left(y_{ikh} - \bar{y}'_{kh} \right)\left(y_{ijh} - \bar{y}'_{jh} \right) u_{ih} \right) ,$$

where

$$\bar{y}'_{kh} = \frac{\sum_{i=1}^{m_h} (y_{ikh} u_{ih})}{\sum_{i=1}^{m_h} (u_{ih})} \qquad \text{(a weighted mean),}$$

and u_{ih} is a weight which is proportional to how well observation i fits in group h. This formula allows the observations more representative of the group in question to receive greater weight in the calculations for the group. This is done in two ways. 1) Since a weighted mean is used, the observations with higher weight (i.e., more representative of the group) will have more influence on the mean value, and 2) the cross product itself is weighted, thus the observations more representative of the group will add more to the sum of the cross products for the group.

T matrix. In fig 4 (note 1) the element in the kth row and jth column of T was shown to be

$$t_{kj} = \sum_{i=1}^{n} ((x_{ik} - \bar{x}_k)(x_{ij} - \bar{x}_j)) .$$

The weighted calculations are as follows. The overall weighted mean (to be used instead of $\bar{x}_k$) is

$$\bar{x}'_k = \frac{\sum_{h=1}^{g} \sum_{i=1}^{m_h} (x_{ikh} u_{ih})}{\sum_{h=1}^{g} \sum_{i=1}^{m_h} (u_{ih})} ,$$

where x_{ikh} is the ith observation of variable k in group h, and u_{ih} is the weight of the ith observation in group h.

The element in the kth row and jth column of T is

$$t_{kj} = \sum_{h=1}^{g} \sum_{i=1}^{m_h} ((x_{ikh} - \bar{x}'_{k})(x_{ijh} - \bar{x}'_{j}) u_{ih}) \quad .$$

This is similar to the calculations for the W matrix, except the weighted overall mean is used instead of the weighted group means.

B matrix. The B matrix is (as with regular discriminant analysis)

$$B = T - W \quad .$$

With the usual discriminant analysis calculations, b_{kj} is equivalent to

$$b_{kj} = \sum_{h=1}^{g} (n_h (\bar{x}_{kh} - \bar{x}_{k}) (\bar{x}_{jh} - \bar{x}_{j})) \quad .$$

In the weighted calculations, b_{kj} is equivalent to

$$b_{kj} = \sum_{h=1}^{g} (p_h (\bar{y}'_{kh} - \bar{x}'_{k}) (\bar{y}'_{jh} - \bar{x}'_{j})) \quad ,$$

where

$$p_h = \mathrm{SUM}_{i=1}^{m_h} (u_{ih}) \quad .$$

Here $\overline{x}'_k$ is the overall weighted mean for variable k (see above), and $\overline{y}'_{kh}$ is the weighted mean for variable k in group h (see above). These formulae are similar to the non-weighted method, except that weighted means are used instead of regular means, and the sum of weights for the group is used instead of the number of observations for the group.

Weighted discriminant analysis with groups directly from the species-site data matrix.

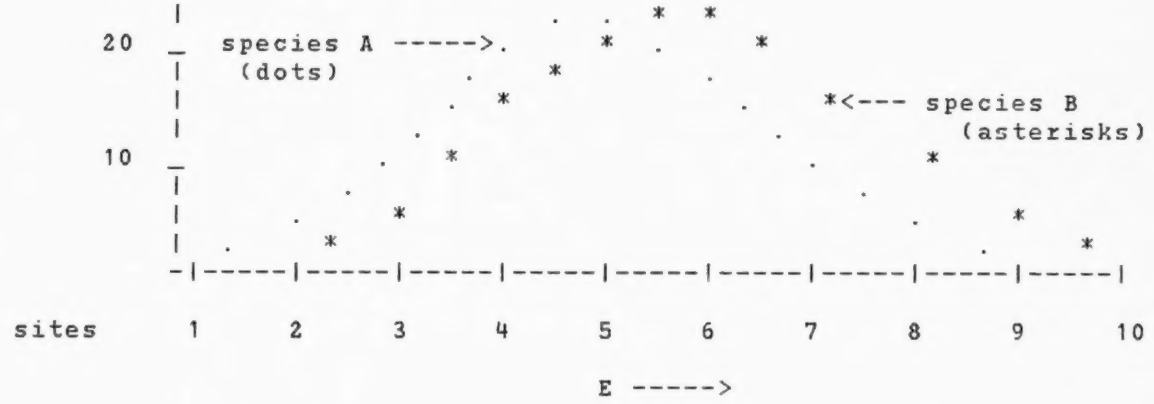
Fig 6A depicts a hypothetical situation with two species (A and B), and 10 potential sampling sites along an environmental gradient (variable E) presumed to be important in the separation (in an ecological sense) of the two species.

If sites 3-8 were sampled, the data might appear as in fig 6B. Normally, the species data would be used to select groups and variable E would be used in the discriminant analysis. Note, however, that as far as group membership is concerned, both groups (one group corresponding to each species) would be identical, since both species occur at all sites. With regular discriminant analysis, these two species could not be differentiated (with respect to variable E), since there would be no between-group variation (the means of variable E for both groups would be the same, see fig 6C).

On the other hand, if weighted calculations are used, the group means can be differentiated as desired. This is illustrated in fig 6D, where the species abundances are used as weights. These are appropriate weights, since the more a species occurs at a site, the more representative of the group (species) is that site. Normally, some standardized measure (such as species-maximum standardized data) of species importance should be used instead of raw abundance counts. This will prevent the more abundant species from dominating the analysis.

Figure 6. Illustration of the advantages of weighted discriminant analysis when groups are chosen directly from the data.

A. two hypothetical species distributed along an environmental gradient.



B. data values

	3	4	5	6	7	8
species A	12	20	22	17	11	4
species B	6	14	20	22	17	12
variable E	2	4	6	8	10	12

sites (columns); species A and species B <-- used as weights

C. group means for variable E

$$\bar{E}_A = \bar{E}_B = 42/6 = 7 \quad \text{(no group differentiation)}$$

D. weighted group means for variable E

$$\bar{E}'_A = \frac{12(2)+20(4)+22(6)+17(8)+11(10)+4(12)}{12+20+22+17+11+4} = 530/86 = 6.16$$

$$\bar{E}'_B = \frac{6(2)+14(4)+20(6)+22(8)+17(10)+12(12)}{6+14+20+22+17+12} = 678/91 = 7.45$$

Even if the groups (species) are not completely overlapping, the weighted method may often have advantages. With the weighted calculations, data from all sites with different species importance values are effectively used in trying to differentiate the groups, whereas with the unweighted calculations, only the sites of non-overlap can be used to differentiate the groups. Since more information is used, the weighted method should often be more robust and accurate.

Weighted discriminant analysis with groups defined from cluster analysis.

Fig 7 shows a hypothetical dendrogram from a hierarchical cluster analysis based on biotic data. From the dendrogram, it can be seen that there are four important pieces of biological information concerning the the groups. These are :

1) group membership, i.e., sites 8 9 10 are in group 1, etc.;

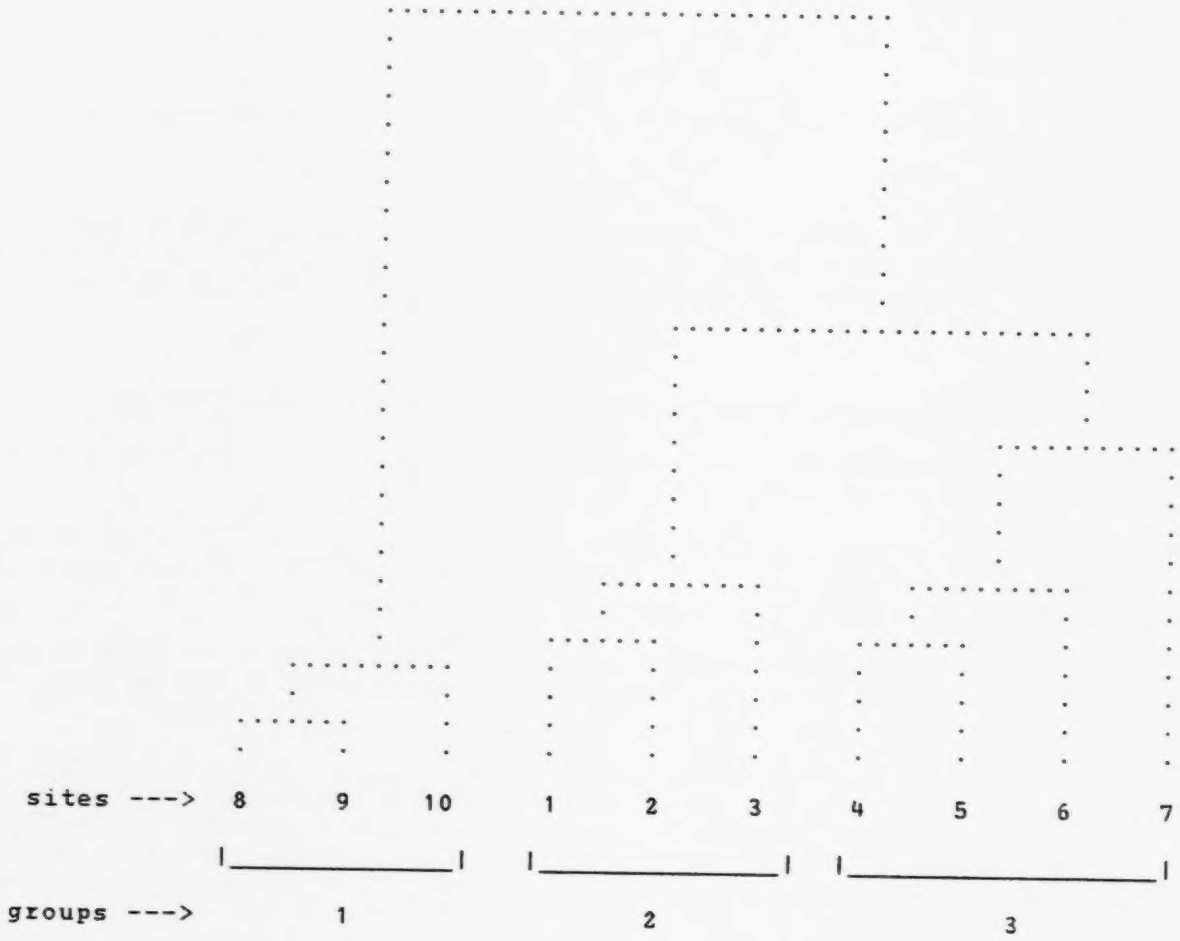
2) strength of group membership, e.g., site 7 is the weakest (most unlike the other members) member of group 3;

3) "cohesiveness" of a group in general, e.g., the members of group 1 are all more similar to each other than is the case with the other groups; and

4) inter-group reltionships. Note that groups 2 and 3 are more closely related to each other than either one is to group 1.

With regular discriminant analysis, only the first (group membership) is input. The other information can be very important. One would want the analysis to emphasize environmental variables which most closely follow all four patterns, not just the first. For example, the three groups in fig 7 might be quite different in levels of both salinity and depth, but groups 2 and 3 are closer in depth to each other than to group 1, and groups 1 and 2 are closer in salinity to each other than to group 3. A good analysis would indicate that depth was more important than salinity (for group separation) since the depth pattern more closely fits the biological pattern (see (4) above). All four pieces of biological information can be input with weighted discriminant analysis. A technique for doing this is shown below.

Figure 7. Hypothetical dendrogram used to illustrate the advantages of weighted discriminant analysis.



The average group-similarity matrix (GRSIM).

The first step is to create a matrix which describes the relationships between every group and every site. This will be called the GRSIM matrix.

All the information required is in the distance (or similarity) matrix on which the cluster analysis is often based. Fig 8A shows the distance matrix from which the dendrogram in fig 7 was made. The elements above the main diagonal are distances and those below are similarities (the distances subtracted from a constant). An element of the GRSIM matrix is simply the average similarity between the site (corresponding to a columns of the matrix) and the group (corresponding to a row) in question. Fig 8C shows some sample calculations, and fig 8B shows the complete GRSIM matrix from the similarities in fig 8A and group membership as in fig 7.

Figure 8. The calculation of the average group-similarity matrix (GRSIM). Data fits the hypothetical dendrogram shown in fig 7.

A. distance (upper-right triangular) and similarity (lower-left triangular) matrices

		sites									
		1	2	3	4	5	6	7	8	9	10
	1		4.0	4.0	10.8	14.7	14.0	20.2	22.0	23.6	24.5
	2	21.0		5.6	10.1	14.2	9.7	18.5	18.2	19.5	20.5
	3	21.0	19.4		7.2	11.0	10.0	17.0	21.1	23.0	23.3
	4	14.2	14.9	17.8		4.0	5.9	10.0	17.3	19.8	19.1
sites	5	10.3	10.8	14.0	21.0		4.0	7.6	19.0	21.1	20.0
	6	11.0	15.3	15.0	19.1	21.0		11.4	22.5	24.9	24.0
	7	4.8	6.5	8.0	15.0	17.4	13.6		15.0	17.3	15.1
	8	3.0	6.8	3.9	7.7	6.0	2.5	10.0		2.5	2.6
	9	1.4	5.5	2.0	5.2	3.9	0.1	7.7	22.5		3.0
	10	0.5	4.5	1.7	5.9	5.0	1.0	9.9	22.4	22.0	

(fig 8 continued on next page)

(fig 8, continued)

B. the average group-similarity matrix (GRSIM)

	sites									
	1	2	3	4	5	6	7	8	9	10
group 1	1.6	5.6	2.8	6.3	5.0	1.2	9.2	22.5	22.3	22.2
group 2	21.0	20.2	20.2	15.6	11.8	10.4	6.4	4.6	3.0	2.2
group 3	10.1	11.9	13.7	18.4	19.8	17.9	15.3	6.6	4.2	5.5
		group 2			group 3				group 1	

C. sample calculations for elements of GRSIM matrix
(s_{ij} = similarity between sites i and j)

site 2 - group 1

$$(s_{2,8} + s_{2,9} + s_{2,10}) / 3 = (6.8+5.5+4.5)/3 = 16.8/3 = 5.6$$

site 3 - group 2

$$(s_{3,1} + s_{3,2}) / 2 = (21+19.4)/2 = 20.2$$

Application of weights.

The elements of the GRSIM matrix are now used as weights in a weighted discriminant analysis. At this point, each site is considered to be a potential member of each group, i.e., each site has a weight indicating how well it fits into each group. In the calculations for group 1, the weights used for each site would be the corresponding elements in the first row of the GRSIM matrix. For group 2, the weights would be in the second row of the GRSIM matrix, and so on.

It can now be shown that all four pieces of biological information about the groups are available to the analysis in the GRSIM matrix of weights.

1) Group membership. Note that for each group (row of the GRSIM matrix), the highest average-similarity values (i.e., weights) are for the actual group members. For example, row 1 represents group 1, which consists of sites 8, 9 and 10. Sites 8, 9, and 10 have the highest weights of all the sites. This would be expected since they are the group members. Thus, group membership is conveyed since the actual group members should have the highest weights in the calculations for the group in question.

2) Strength of group membership. Site 7 is the "weakest" of the actual members of group 3. The average-similarity values (row 3, fig 8B) in the GRSIM matrix for the members of group 3 (sites 4-7) are 18.4, 19.8, 17.9, and 15.3. Note that the lowest value is 15.3, which corresponds to site 7. Thus, of the actual members of group 3, site 7 will receive the lowest weight, which is consistent with its biological relationship to the rest of the group members.

3) "Cohesiveness" of a group in general. Group 1 has the highest internal biological similarity of the three groups (connected lowest on the dendrogram). The average similarities of the members of group 1 with their own group are 22.5, 22.3, and 22.2. The average similarities of the members of group 2 with their own group are 21.0, 20.2, and 20.2; the average similarities of group 3 with its own members are 18.4, 19.8, 17.9 and 15.3. Of the three groups, the members of group 1 have the highest average similarity values with their own group. This results in group 1 receiving more overall weight per site than the other groups. This makes sense since group 1 is closer to a real homogenous group than are the other groups. This can be important since the analysis will try to minimize the within-group variation in the discriminant space (along with the maximization of the between-group variation). The lower weights for the "looser" groups will prevent the analysis from emphasizing variables which will minimize the distance (in the discriminant space) between sites which are not really that biologically similar. This same arguement applies

to (2) above.

4) Inter-group relationships. Groups 2 and 3 are biologically more similar to each other than they are to group 1 (fig 7). This information is also available in the GRSIM matrix. In the row for group 2 (row 2, GRSIM matrix), the sites that are in group 3 (sites 4-7) show higher average similarity values (15.6, 11.8, 10.4, and 6.4) than do the sites in group 1 (4.6, 3.0, and 2.2). Also, in row 3, the values for group 2 (10.1, 11.9, 13.7) are higher than those for group 1 group 1 (6.6, 4.2, 5.5). This indicates that in the calculations for group 2, the sites in group 3 will get more weight than the sites in group 1, and also that the group 3 calculations will contain relatively higher weights for group 2. Thus, it can be seen that the more similar groups will have higher average similarities for each other's members.

It should be noted that this GRSIM approach is only one of many possibile techniques to obtain weights for the sites. All that is required is a GRSIM-type matrix which expresses the relationships between the defined groups and each site. For example, probabilities of group membership could be used instead of average similarities.

Weighted discriminant analysis with no groups defined.

One way to avoid defining groups at all is to consider each site a group by itself. When this is done, the GRSIM matrix will simply be the inter-site similarity matrix. Weighted discriminant calculations are then carried out with the GRSIM matrix as weights in the manner described above.

This is a good way to directly analyze the distance (or similarity) matrix (i.e., the biological patterns) without any prior clustering procedure. This has the advantage of saving the clustering computation time and avoiding any errors (of group membership) that the clustering technique may introduce. (However, the weighted discriminant calculations themselves will be longer, since more groups will be involved). Such a technique also eliminates the burden of deciding where and how to define group membership from the clustering results.

The fact that no group membership need be defined suggests that weighted discriminant analysis could in some cases be a replacement for a canonical correlation analysis, which is used to study the relationships between two sets of variables. Gauch and Wentworth (1976) demonstrate how the strict assumptions of linearity make canonical correlations unsuitable for some types of ecological data. Weighted discriminant analysis only requires that the variables used in the calculation of the sum of squares and cross-products matrices (W, B, T) linearly separate the groups (observations in this case). This assumption can easily be met with most kinds of biotic-environmental data sets. When some variables separate the observations in a monotonic but non-linear fashion, a transformation of the corresponding variable(s) will usually make the relationships more linear.

DISCRIMINANT ANALYSIS WITH SPECIES AS VARIABLES.

When groups of biologically similar sampling sites have been defined (usually by cluster anaysis), discriminant analysis with the species importance values as variables has been used (or tested for use) to:

1) determine which species were mainly involved in causing the group separations (Cassie, 1972; Gringal and Ohmann, 1975);

2) observe the relatinships between the groups in the discriminant score plots (Norris and Barkham, 1970; Cassie, 1972; Gringal and Ohmann, 1975; Holland and Polgar, 1976; Holland et al, 1977);

3) use the results as an indirect ordination technique in the same manner that principal components, reciprocal averaging, polar ordination, multidimensional scaling, etc. are used with biological data (Kessell and Whittaker, 1976); and

4) test the significance of the group separation.

Here also, the regular discriminant analysis only considers group membership, while the weighted version can use additional intra- and inter-group biological information in the calculations. This additional information input should give better results in most cases when (1), (2), or (3) above, is the goal of the anaysis.

As far as testing the significance of group separation is concerned, weighted discriminant analysis is presently of little help since the groups are, in effect, overlapping (this violates an assumption of the tests). Even without overlap, it is doubtful that the significance tests would be completely valid due to the usual nature of species abundance data. For example, one of the assumptions of the method (when statistical tests are applied) is that the within-group dispersion matrices (W matrix divided by D.F.) are statistically equal (Green, 1971). If the survey in question covers more than a single homogeneous habitat, then one would expect some species to occur in some groups but not in others. In the groups where such a species occurs, the dispersions would be some value other than zero; but in groups where the species is absent, the dispersions would be zero. This alone would lead to quite different within-group dispersion matrices for the various groups. In the experience of the author, whether species or environmental data are used in the discriminant analysis, this assumption is almost always violated, but the extent of the violation is greater with species data.

On the other hand, discriminant analysis can be fairly robust even when the within-group dispersion matrices are not statistically equal (Cooley and Lohnes, 1971; Pimentel and Frey, 1978). The method becomes more robust as the group sample sizes become larger and more equal (Ito and Schull, 1964). It is not known how the robustness is affected by truncated variables (e.g., some species-count data).

If the groups are defined using the species data (as would be the case in a cluster analysis), and then these groups are used in a discriminant analysis with species as variables, the usual probability tests are invalid even if all the other assumptions are met. This is because the statistical tests assume that the groups were defined by a planned, a priori procedure (Sokal and Rholf, 1969; 226-227). When the data are used to suggest the groups, this assumption is obviously violated.

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APPENDIX A

DISCRIMINANT ANALYSIS (UNWEIGHTED) - SAMPLE CALCULATIONS

A. Data matrix

$$\begin{array}{cc|cc|c}
 & & \multicolumn{2}{c}{\text{variable}} & \\
 & & 1 & 2 & \\
\hline
 & 1 & 1 & 8 & \text{group 1} \\
 & 2 & 3 & 5 & \\
\cline{3-4}
\text{site} & 3 & 5 & 7 & \text{group 2} \\
 & 4 & 7 & 6 & \\
\hline
\end{array}$$

B. Calculation of the pooled W matrix

1. group means

$$\begin{array}{c|cc|}
 & \multicolumn{2}{c}{\text{variable}} \\
 & 1 & 2 \\
\hline
\text{group 1} & 2 & 6.5 \\
\text{group 2} & 6 & 6.5 \\
\hline
\end{array}$$

2. group data centered (subtract mean value) by group means

$$\begin{array}{cc|cc|c}
 & & \multicolumn{2}{c|}{\text{variable}} & \\
 & & 1 & 2 & \\
\hline
 & 1 & -1 & 1.5 & \\
 & 2 & 1 & -1.5 & C_1 \\
\cline{3-4}
\text{site} & 3 & -1 & .5 & \\
 & 4 & 1 & -.5 & C_2 \\
\hline
\end{array}$$

3. W matrix for group 1

$$W_1 = C'_1 C_1 = \begin{bmatrix} -1 & 1 \\ 1.5 & -1.5 \end{bmatrix} \times \begin{bmatrix} -1 & 1.5 \\ 1 & -1.5 \end{bmatrix} = \begin{bmatrix} 2 & -3 \\ -3 & 4.5 \end{bmatrix}$$

3. W matrix for group 2

$$W_2 = C'_2 C_2 = \begin{bmatrix} -1 & 1 \\ .5 & -.5 \end{bmatrix} \times \begin{bmatrix} -1 & .5 \\ 1 & -.5 \end{bmatrix} = \begin{bmatrix} 2 & -1 \\ -1 & .5 \end{bmatrix}$$

5. pool

$$W = W_1 + W_2 = \begin{bmatrix} 2 & -3 \\ -3 & 4.5 \end{bmatrix} + \begin{bmatrix} 2 & -1 \\ -1 & .5 \end{bmatrix} = \begin{bmatrix} 4 & -4 \\ -4 & 5 \end{bmatrix}$$

C. Calculation of the T matrix

1. over-all means

$$\bar{X}_1 = 4$$

$$\bar{X}_2 = 6.5$$

2. data centered by over-all means

$$\begin{array}{cc|cc|c} & & \multicolumn{2}{c}{\text{variable}} & \\ & & 1 & 2 & \\ & 1 & -3 & 1.5 & \\ \text{site} & 2 & -1 & -1.5 & \text{matrix Z} \\ & 3 & 1 & .5 & \\ & 4 & 3 & -.5 & \end{array}$$

3. T matrix

$$T = Z'Z = \begin{bmatrix} -3 & -1 & 1 & 3 \\ 1.5 & -1.5 & .5 & -.5 \end{bmatrix} \times \begin{bmatrix} -3 & 1.5 \\ -1 & -1.5 \\ 1 & .5 \\ 3 & -.5 \end{bmatrix} = \begin{bmatrix} 20 & -4 \\ -4 & 5 \end{bmatrix}$$

D. Calculation of the B matrix

1. difference method

$$B = T - W = \begin{bmatrix} 20 & -4 \\ -4 & 5 \end{bmatrix} - \begin{bmatrix} 4 & -4 \\ -4 & 5 \end{bmatrix} = \begin{bmatrix} 16 & 0 \\ 0 & 0 \end{bmatrix}$$

2. direct method

e.g. $$b_{12} = \mathrm{SUM}_{h=1}^{2} \left(n_h \left(\bar{x}_{1h} - \bar{x}_1 \right)\left(\bar{x}_{2h} - \bar{x}_2 \right) \right) ,$$

$$= 2(2-4)(6.5-6.5) + 2(6-4)(6.5-6.5) = 0$$

E. Eigenvalues and eigenvectors of $W^{-1} B$

1. eigenvalue $L_1 = 20$

2. eigenvector $$A_1 = \begin{array}{cl} \text{axis 1} & \\ \left[\begin{array}{c} .78087 \\ .62469 \end{array} \right] & \begin{array}{l} \text{variable 1} \\ \text{variable 2} \end{array} \end{array}$$

note: Only one axis was defined since there are only 2 groups.

APPENDIX A (CONTINUED)

F. Calculation of scores

$$S_1 = X A_1 = \begin{bmatrix} 1 & 8 \\ 3 & 5 \\ 5 & 7 \\ 7 & 6 \end{bmatrix} \times \begin{bmatrix} .78087 \\ .62469 \end{bmatrix} = \begin{array}{cc} \text{axis 1} & \\ \left[\begin{matrix} 5.77840 \\ 5.46608 \\ 8.27722 \\ 9.21428 \end{matrix}\right] & \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \end{matrix} \end{array} \text{site}$$

G. Coefficients of separate determination

1. put eigenvector in diagonal matrix of zeros off diagonal

$$Z_1 = \begin{bmatrix} .78087 & 0 \\ 0 & .62469 \end{bmatrix}$$

APPENDIX A (CONTINUED)

2. calculate coefficients

$$D_1 = Z_1 T Z_1 U = \begin{bmatrix} .78087 & 0 \\ 0 & .62469 \end{bmatrix} \times \begin{bmatrix} 20 & -4 \\ -4 & 5 \end{bmatrix} \times \begin{bmatrix} .78087 & 0 \\ 0 & .62469 \end{bmatrix} \times \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

$$= \begin{array}{l} \begin{bmatrix} 10.243953 \\ 0 \end{bmatrix} \end{array} \begin{array}{l} \text{variable 1} \\ \text{variable 2} \end{array}$$

H. Standardized coefficients (by total SD)

1. coefficient for variable 1 on axis 1

$$e_{11} = a_{11} (t_{11} / (n-1))^{1/2}$$

$$= .78087(20/3)^{1/2} = 2.01620$$

2. coefficient for variable 2 on axis 1

$$e_{21} = a_{21} (t_{22} / (n-1))^{1/2}$$

$$= .62469(5/3)^{1/2} = .80647$$

APPENDIX A (CONTINUED)

I. Standardized coefficients (by within SD)

2. coefficient for variable 1 on axis 1

$$f_{11} = a_{11}(w_{11}/(n-g))^{1/2}$$

$$= .78087(4/2)^{1/2} = 1.10432$$

2. coefficient for variable 2 on axis 1

$$f_{21} = a_{21}(w_{22}/(n-g))^{1/2}$$

$$= .62469(5/2)^{1/2} = .98772$$

APPENDIX B

WEIGHTED DISCRIMINANT ANALYSIS - SAMPLE CALCULATIONS

A. Data matix - start with the same data as in the unweighted calculations

$$\begin{array}{cc|cc|}
 & & \multicolumn{2}{c}{\text{variable}} \\
 & & 1 & 2 \\
\hline
 & 1 & 1 & 8 \\
\text{site} & 2 & 3 & 5 \\
 & 3 & 5 & 7 \\
 & 4 & 7 & 6 \\
\hline
\end{array}$$

B. Matrix of weights (could be from relative species abundances or a GRSIM-type matrix, etc.)

$$\begin{array}{c|cccc|}
 & \multicolumn{4}{c}{\text{site}} \\
 & 1 & 2 & 3 & 4 \\
\hline
\text{group 1} & .1 & .2 & .8 & .7 \\
\text{group 2} & .8 & .9 & .1 & .3 \\
\hline
\end{array}$$

C. Expanded data matrix

Note that there are four sites in each group (no site has a weight of zero). Therefore the data matrix would appear as such:

		variable		
		1	2	
site	1	1	8	group 1
	2	3	5	
	3	5	7	
	4	7	6	
	1	1	8	group 2
	2	3	5	
	3	5	7	
	4	7	6	

D. Calculation of the pooled W matrix

1. weighted group means

	variable 1	variable 2
group 1	5.33333	6.44444
group 2	2.90476	6.38095

e.g.

$$\bar{y}'_{11} = \frac{\sum_{i=1}^{4} (y_{i11}\ u_{i1})}{\sum_{i=1}^{4} (u_{i1})}$$

$$= \frac{1(.1) + 3(.2) + 5(.8) + 7(.7)}{.1 + .2 + .8 + .7} = 5.33333$$

APPENDIX B (CONTINUED)

2. center group data by weighted group means

		variable		
		1	2	
site	1	-4.3333	1.5556	group 1
	2	-2.3333	-1.4444	
	3	-.3333	.5556	
	4	1.6667	-.4444	
	1	-1.9048	1.6191	group 2
	2	.0952	-1.3810	
	3	2.0952	.6191	
	4	4.0952	-.3810	

3. W matrix for group 1 (W_1)

		variable	
		1	2
variable	1	5.00000	-.66668
	2	-.66668	1.04444

e.g. $w_{121} = \text{SUM}_{i=1}^{4} \left(\left(y_{i11} - \bar{y}'_{11} \right)\left(y_{i21} - \bar{y}'_{21} \right) u_{i1} \right)$,

$= (-4.3333)(1.5556)(.1) + (-2.3333)(-1.4444)(.2)$
$+ (-.3333)(.5556)(.8) + (1.6667)(-.4444)(.7)$

$= -.67409 + .67404 - .14815 - .51848$

$= .-66668$

4. W matrix for group 2 (W_2)

$$\begin{array}{llcc} & & \multicolumn{2}{c}{\text{variable}} \\ & & 1 & 2 \\ \text{variable} & 1 & 8.38096 & -2.92381 \\ & 2 & -2.92381 & 3.89524 \end{array}$$

$$\text{e.g.} \quad w_{122} = \sum_{i=1}^{4} \left((y_{i12} - \bar{y}'_{12})(y_{i22} - \bar{y}'_{22}) u_{i2} \right) ,$$

$$= (-1.9048)(1.6191)(.8) + (.0952)(-1.381)(.9) + (2.0952)(.6191)(.1) + (4.0952)(-.381)(.3)$$

$$= -2.46710 - .11832 + .12969 - .46808$$

$$= -2.92381$$

5. pool

$$W = W_1 + W_2 = \begin{array}{ccll} \multicolumn{2}{c}{\text{variable}} & & \\ 1 & 2 & & \\ 13.38096 & -3.59049 & 1 & \text{variable} \\ -3.59049 & 4.93968 & 2 & \end{array}$$

APPENDIX B (CONTINUED)

E. Calculation of the T matrix

1. over-all weighted means

a. for variable 1

$$\bar{x}'_1 = \frac{\mathrm{SUM}_{h=1}^{2}\ \mathrm{SUM}_{i=1}^{4}\ (x_{i1h}\ u_{ih})}{\mathrm{SUM}_{h=1}^{2}\ \mathrm{SUM}_{i=1}^{4}\ (u_{ih})}$$

$$= \frac{1(.1)+3(.2)+5(.8)+7(.7)+1(.8)+3(.9)+5(.1)+7(.3)}{.1+.2+.8+.7+.8+.9+.1+.3}$$

$$= 15.7/3.9 = 4.02564$$

b. similarly, for variable 2

$$\bar{X}'_2 = \frac{8(.1)+5(.2)+7(.8)+6(.7)+8(.8)+5(.9)+7(.1)+6(.3)}{3.9}$$

$$= 6.41026$$

APPENDIX B (CONTINUED)

2. center data by over-all weighted means

```
                        variable

                      1            2
                .......................
          1     . -3.02564     1.58974 .
          2     . -1.02564    -1.41026 .      group 1
          3     .   .97436      .58974 .
          4     .  2.97436     -.41026 .
 site           .---------------------.
          1     . -3.02564     1.58974 .
          2     . -1.02564    -1.41026 .      group 2
          3     .   .97436      .58974 .
          4     .  2.97436     -.41026 .
                .......................
```

3. T matrix

```
                         variable

                        1           2
                   .....................
              1    . 19.09744 -3.44102 .
 variable          .                   .
              2    . -3.44102  4.94359 .
                   .....................
```

e.g. $t_{12} = \sum_{h=1}^{2} \sum_{i=1}^{4} \left((x_{i1h} - \bar{x}'_{1})(x_{i2h} - \bar{x}'_{2}) u_{ih} \right)$

$$= (-3.02564)(1.58974)(.1) + (-1.02564)(-1.41026)(.2) + (.97436)(.58974)(.8) + (2.97436)(-.41026)(.7) + (-3.02564)(1.58974)(.8) + (-1.02564)(-1.41026)(.9) + (.97436)(.58974)(.1) + (2.97436)(-.41026)(.3)$$

$$= -3.44102$$

F. Calculation of the B matrix

1. difference method

$$B = T - W = \begin{array}{ccc} \multicolumn{2}{c}{\text{variable}} & \\ 1 & 2 & \\ \hline 5.71648 & .14947 & 1 \\ .14947 & .00391 & 2 \\ \hline \end{array} \quad \text{variable}$$

2. direct method

e.g.

$$b_{12} = \mathrm{SUM}_{h=1}^{2} \left(p_h \left(\bar{y}'_{1h} - \bar{x}'_{1} \right) \left(\bar{y}'_{2h} - \bar{x}'_{2} \right) \right) ,$$

$$= (1.8)(5.33333-4.02563)(6.44444-6.41026)$$
$$+ (2.1)(2.90476-4.02564)(6.38095-6.41026)$$

$$= .14944$$ (differs in the fifth decimal from the difference method - due to rounding error)

G. Once the W, B and T matrices are calculated, the analysis proceeds as with unweighted discriminant analysis. When calculating the scores, use the original unexpanded data matrix, since only one score per site is required.